

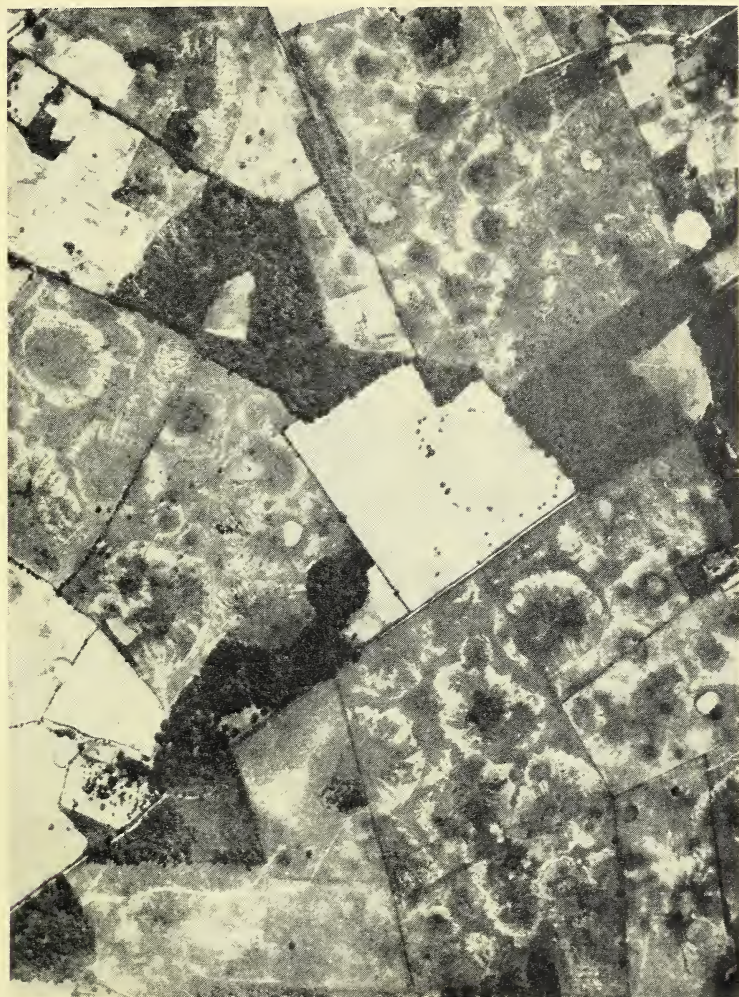
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Soil Erosion in the Karst Lands of Kentucky



UNITED STATES DEPARTMENT OF AGRICULTURE
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FRONT COVER.—*A typical erosion pattern in the limestone section of western Kentucky, as seen from an airplane. Erosion is concentrated in circular bands on the margins of the solution depressions and is so serious that most of the fields are no longer cultivated. The erosion scars are conspicuous in pasture and idle land but are less apparent in the freshly plowed fields. This area is in Meade County, about 2 miles west of Garnettsville.*



SOIL EROSION IN THE KARST LANDS OF KENTUCKY

Physiographic Conditions Affecting Erosion and Land Use in Areas Underlain by Soluble Limestone

By S. N. DICKEN, *soil conservationist*, and H. B. BROWN, JR., *junior soil conservationist, Section of Climatic and Physiographic Research, Division of Research, Soil Conservation Service*

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THE KARST LANDS

Large areas in several of the Eastern States are underlain by soluble limestone, the natural erosion of which produces distinctive land forms not found on insoluble rock. Two of the best developed and most extensive of these areas are in the limestone lands of southern and western Kentucky (fig. 1). The surface there has the general appearance of a rolling plain, but closer inspection reveals that it is pitted with solution depressions similar to rude cisterns, hornlike funnels, and broad, shallow basins. Surface watercourses and true valleys are almost absent, since the run-off quickly flows or seeps downward in the hollows and drains away through the extensive underground circulation. A land surface of this type, in which solution by percolating water is the dominant sculpturing process, is called karst, a term originally applied to a large limestone area along the northern part of the eastern coast of the Adriatic Sea.¹ From that region the term has been extended to all similar areas underlain by soluble limestone bedrock and having underground drainage, caverns, and surface depressions produced by solution (6, fig. 27).²

¹ The European karst is best developed in the Provinces of Dalmatia and Croatia in Yugoslavia and in the Province of Istria, now part of Italy but formerly belonging to Austria.

² Italic numbers in parentheses refer to Literature Cited, p. 59.

In the karst lands of Kentucky, the solution depressions range from pits a few feet in diameter to large elongate hollows almost 1 mile wide. Depressions of one type are commonly about 30 feet deep and 60 feet wide and are shaped like the horn of a trumpet. Others are broad, shallow basins with gently sloping margins. Between the depressions there is little level land—only rounded knolls and hummocky, winding ridges. Each pit or hollow has, or formerly

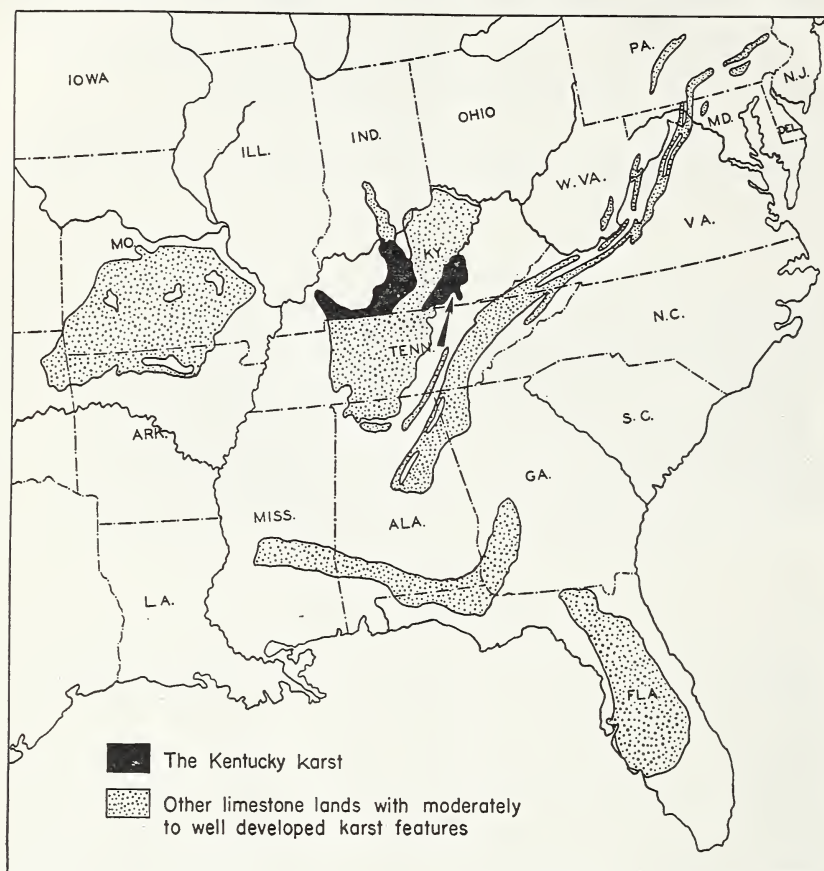


FIGURE 1.—Index map showing the location of the Kentucky karst and other areas of soluble limestone south of the glacial border in the eastern United States. The crescent-shaped area in western Kentucky is shown in more detail in figure 4. The smaller black area borders the Cumberland River, and the arrow indicates the approximate location of Elk Spring Valley, described on pages 47–53.

had, a bottom outlet connecting with the subterranean channels. Some of the outlets have become blocked, however, and the water now can escape only by slow percolation downward into the underground circulation. In other depressions the blockage is complete and ponds have been formed. Beneath the land surface large channels and caverns have been dissolved out of the limestone by percolating water, which is made more active as a solvent by the addition of weak acids, some derived from the atmosphere and some from vege-

tation. After passing through underground channels, the water sometimes reappears at the surface as a spring. It may then join a major river or, after flowing on the surface for a short distance, may suddenly dip back underground. The slopes bordering the solution depressions are usually short, but, even so, some parts of the area are seriously eroded, as is shown in the aerial photograph on the front cover.

Other parts of the great limestone region that extends from southern Indiana (3, p. 393) through Kentucky and Tennessee to northern Alabama and from the Cumberland Mountains to the lower Tennessee River (fig. 1) also have well-developed karst land forms. There are extensive areas, however, such as the Bluegrass section of Kentucky, where solution is an active process but is not dominant in shaping the land surface.

Karst features also characterize certain other parts of the country. The floors of many of the large valleys in the Appalachian region are underlain by soluble calcareous rocks. Although these detached areas are usually rather small, many of them resemble the Kentucky karst and equal it in the variety of solution forms. In the Coastal Plain of Florida (7) and Georgia (4) the limestone solution features usually are covered with a veneer of sand, and although the land forms themselves are essentially of the karst type, soil conditions are very different from those in Kentucky. In the limestone areas of the Ozarks, in Missouri and Arkansas, solution forms are moderately well developed, and much of the drainage passes off through underground channels. The Ozark limestones contain more chert than the limestones of Kentucky and therefore probably have a lower erosion hazard (27, pp. 16, 36).

Altogether, more than 5,000,000 acres of farming land in the southeastern United States are subject to destructive erosion that may be attributed directly to the existence of karst forms. A much larger area of limestone land is subject to similar but less pronounced karstic erosion. These areas are widely distributed in more than 14 States (fig. 1), and although their surface conditions vary, the residual limestone soils and the risks peculiar to the karst solution forms are common to them all. The Kentucky karst has a sufficient variety of land forms and soil-erosion problems to be representative of conditions in the limestone lands of the entire southeastern United States.

Our knowledge of the peoples who lived in Kentucky before white settlement is very scanty. Hoes, spades, and other artifacts indicate that the prehistoric men of that section did not subsist entirely on a hunting-gathering economy. Most of their cultivation was done on bottom lands along the rivers (36, p. 180), however, and their primitive tools did not permit vigorous or intensive cultivation, so it is unlikely that their agriculture had much effect in accelerating erosion.

Immediately before the coming of the white man, Kentucky was a favorite hunting ground for the Shawnees and other Indians but seems to have been occupied permanently by no one tribe (15, p. 525; 11, p. 306). Although the Indians probably did not cause any extensive soil erosion, they did effect certain changes in the landscape by burning over the ground in the early spring (16, p. 36). This practice, probably intended to make the land more attractive for

game by destroying the old grass and preparing the way for fresh shoots, may have induced some soil wastage on the steeper escarpment slopes.

The first white settlers to see the undulating limestone country of western Kentucky were not concerned with soil erosion. The porous virgin soil, penetrated by interlacing roots and covered with tall grass or forest, could absorb precipitation and lead it gradually underground. It was reported that in places the soils were so soft that horses sank to their fetlocks (*12, p. 2*). There were few if any gullies or scars on the slopes, and no apparent indication that the soil would ever wash away. The land was covered with dense vegetation—oak forest on the hilly margins and tall grass on the smoother parts known to the early settlers as barrens³ (*8; 20, p. 183; 28, p. 123*). As the land was brought under cultivation, however, a large proportion of the natural vegetation was removed and the equilibrium of run-off, absorption, and evaporation was destroyed. Local surface wash was enormously increased, and serious soil erosion began.

The history of karst areas of other countries, where cultivation has been carried on for many centuries, should serve as a warning of the future of our own limestone lands. The karst lands on the peninsula of Istria and in other areas bordering the Adriatic Sea have been occupied by man since the dawn of history. As a result of cutting the forests for ship timbers and firewood or of clearing the land for cultivation, some of the areas lost their soil so long ago that many people regard the bare rock as a natural condition. It is said of the Istrian karst:

Formerly covered with forest, it presents today only an immense desert where one sees absolutely nothing but rocks. For a long time the Austrian Government has endeavored to improve these lands by reforestation but its efforts up to the present [1870] have failed * * * (*2, p. 69*).

Portions of the European karst are still under cultivation. This, probably, is made possible by the garden type of agriculture widely practiced in the Mediterranean lands. Intensive spade and hoe cultivation limited to the most favorable spots is less damaging than the general use of the plow. Nevertheless, parts of the Adriatic karst present—

* * * a picture of the dreariest waste, for only the scantiest vegetation flourishes here. With the exception of a few places where oak and horn-beam grow, not only is forest lacking but one might almost say that the karst is entirely without vegetation. Only here and there stands out a little weed, or a thicket from the limestone piles. The land is scarcely suitable for the cultivation of grain or raising cattle. In the depressions only a few spots can be found which afford a meager return or here and there a favorable place for a single grape-vine * * * (*1, p. 251*).

Considering the similarity of this European karst region to our own in rainfall, original forest, and rock type and taking into account the damage wrought in a century and a half in our own limestone lands, it is not inconceivable that the American karst should suffer a fate similar to that of the European. The most eroded parts of

³ The term "barrens" was used by the early settlers of Kentucky, Tennessee, and Indiana in the sense of "prairie." To some the term undoubtedly implied infertility, but this fact had little, if any, effect in delaying settlement.

the Kentucky karst already approach the "patch" cultivation described in the above quotation.

PHYSICAL BACKGROUND OF THE KENTUCKY KARST

The part of Kentucky that best illustrates karst features forms an irregular crescent, bordering the Western Coal Basin (fig. 1). Another similar area, extending from Clinton County to Lincoln County, lies to the east, near the Cumberland River. In both areas the quality of the karst is highly variable. In its most characteristic development it is a rolling solution plain of the type previously described. Where solution is somewhat less effective the plain is much smoother, and where the karst has developed on a dissected plateau the ridges of which are capped with sandstone the surface is rugged and includes many large cave-in depressions (fig. 2).

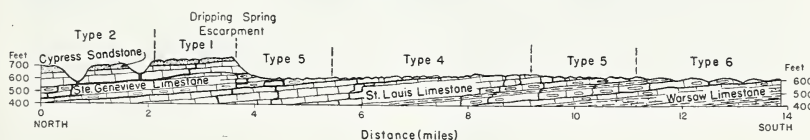


FIGURE 2.—Profile section of the Kentucky karst in the vicinity of Mammoth Cave, Edmonson County. The Cypress sandstone caps the cavernous Ste. Genevieve limestone. Below this is the St. Louis limestone, which is underlain by the less soluble Warsaw limestones and shales. The numerals above the profile indicate the various types of karst, corresponding to table 1 and the legend of figure 4.

These variations in the surface of the limestone lands are closely related to differences in rock quality. As karst forms depend on the presence of soluble limestone, the initial development of the karst in Kentucky took place where percolating waters began to form solution cavities in the limestone underlying the sandstone capping of the plateau. The dissected surface of the plateau still represents the early stages of karst development. In areas where the sandstone has been stripped away, solution forms are of a different type, indicating a more advanced stage of the karst landscape. The final or degenerating stage is reached where erosion has penetrated downward to the shaly limestone. This rock is less soluble, hence underground percolation is diminished and karst forms are shallower. In crossing from the inner to the outer sides of the karst crescent in the vicinity of Mammoth Cave (fig. 2), one observes successively older stages of karst development, owing to the exposure of successively lower geologic formations. In approaching the edge of the sandstone plateau, one observes, first, the disappearance of surface streams; then, on the soluble limestones below the escarpment, a sequence of karst forms similar to that in figure 3; and finally, on the insoluble rocks, the return of surface streams.

If the quality of each bed of rock were uniform throughout the entire area, the various kinds of karst would appear in even, parallel bands. The degree of solubility, however, varies from place to place in each layer of rock and is accompanied by changes in the characteristics of the karst surface. For this reason it is necessary to understand the sequence of geologic formations and their horizontal variations.

The sandstones, limestones, and shales in the karst lands of western Kentucky dip toward the Western Coal Basin, producing the effect of a stack of successively smaller saucers. The youngest and highest formation in this immediate area, the Cypress sandstone, is therefore on the inner margin of the karst crescent (fig. 2). The soluble Ste. Genevieve and St. Louis formations come next in order. Along the outer margin of the crescent are the older shaly limestones and shales of the Warsaw formation. All of these formations were deposited beneath the waters of a shallow sea which once extended northward into this area from the Gulf of Mexico. Regional uplift of the lands drained off the water, and warping of the surface as it was raised produced a high axis, passing roughly north-south through Cincinnati, and a depression, the Western Coal Basin, farther west.

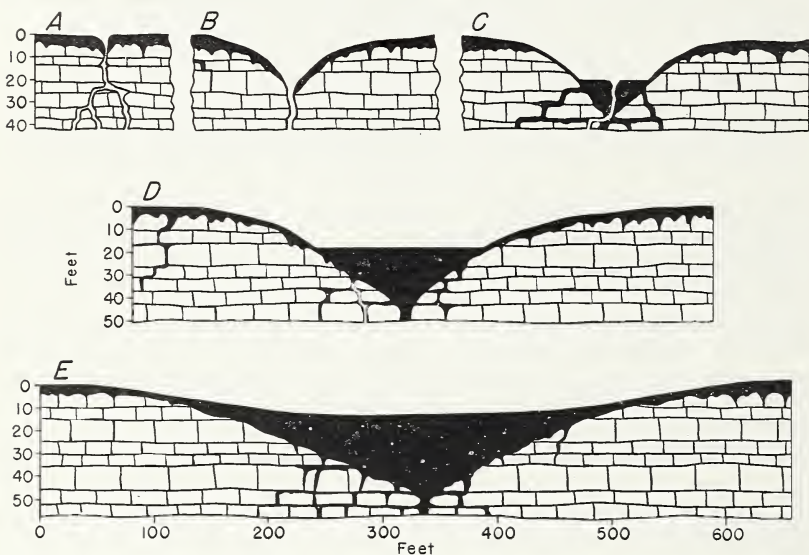


FIGURE 3.—Diagrammatic profiles of karst forms: A, Cistern sink; B, small, active doline; C, loine with bottom partly filled with alluvium; D, later stage of doline; E, basin. Note that the convex slopes of the dolines make a definite angle with the filled bottom. The shape of a doline may be compared to that of a trumpet bell. The basin slopes are concave, similar to shallow saucers, with no sharp line marking the filled bottom.

No brief descriptions of rock types will hold for all the area of the karst. The descriptions given below, especially applicable to the vicinity of Mammoth Cave, are intended to give a general idea of the different types and their normal relation to the karst forms. Variations are common, even within one horizon, and local descriptions will be given where there is special need for them.

Sandstones, shales, and limestones of the Chester group surround the Western Coal Basin in a belt that ranges in width from 5 to 10 miles. Although there is some solution and underground circulation in this series, most of the limestones are too thin to permit more than slight development of karst forms. Aside from minor features, only one formation of the Chester group, the Cypress sandstone, is significant in the karst.

The Cypress is a massive, medium-grained sandstone, usually not highly indurated, ranging in thickness from 40 to 80 feet. The

cementing material is in part calcium carbonate and usually also in part brown iron oxide. These constituents of the cement account for the ease with which the rock is disintegrated by underground waters and for the characteristic buff color of exposures. The sandstone weathers to a medium, even-textured sand of subangular quartz grains. In a few localities, where the white color indicates deficiency of cementing material, the rock crumbles especially easily.

The Ste. Genevieve and St. Louis limestones lying beneath the Cypress sandstone, and known collectively as the Mammoth Cave limestone, total more than 500 feet in thickness and are the principal formations upon which the karst is developed. Their outcrop ranges in width from 20 to 30 miles. The Ste. Genevieve (fig. 2) is generally more soluble than the St. Louis (21, p. 103) but contains relatively insoluble lenses and nodules of chert, which appear as fragments in the residual soils. The St. Louis is a fine gray limestone with bands of nodular chert and a few isolated layers of clay. The formation is 300 or more feet in thickness, and its character differs in different horizons. The upper part is more soluble; the lower contains layers of chert and shale and considerable nodular chert. The chert remains after the removal of the soluble material, and its accumulation in the soil gives a characteristic appearance to the surface.

Below the St. Louis limestone is the Warsaw formation. In western Kentucky it is usually an impure limestone, the impurities consisting of shaly beds, cherty layers, and geodes. The top of the formation in southern Kentucky is a coarse, dark bluish-gray limestone, the color forming a partial basis for distinguishing the Warsaw from the St. Louis limestone. The chert lies in layers or bands, generally discontinuous and usually not more than 1 foot thick, or appears as cherty nodules, which weather into subspherical masses. Although the lower limit of activity of the karst-forming process is not precisely at the St. Louis-Warsaw contact, solution channels rarely extend far down into the Warsaw formation. This is true, apparently, not because the upper phases of the Warsaw are insoluble, but because fissures must be opened to a considerable depth below the surface before the karst-forming process can function on a large scale.

The Dripping Spring escarpment (9, p. 539; 17, p. 43), about 200 feet high, marks the line of contact between the sandstone of the dissected plateau and the relatively pure Mammoth Cave limestones, in which karst forms are dominant (fig. 2). The escarpment may be divided into three parts: The nearly vertical sandstone cliff, marking the edge of the capping sandstone; the talus slope, steep and sandy; and the lower, gentler limestone slope, which is the only portion usually cultivated. The escarpment is very irregular in plan. Its dissection was begun by streams that flowed on the old prekarst upland, and the work has been continued by the solvent action of underground waters. In many places the escarpment includes a strip of land 1 to 5 miles wide, made up of "inliers" produced by the collapse of cave roofs, "outliers" that appear as isolated knobs and ridges,⁴ and other features that cannot be represented on a

⁴JILLSON, W. R. GEOLOGIC MAP OF KENTUCKY. Ky. Geol. Survey. ser. 6. Scale: 1:500,000. 1929.

small-scale map. Below the Dripping Spring escarpment is the rolling solution plain, the most complete development of the karst. Except where dissected by through-flowing streams, this plain is much smoother than the sandstone upland. Another escarpment, capped with limestone and even more irregular than the Dripping Spring, borders the plain on the east and south, but lies beyond the limits of the karst.

KARST TYPES

When the sandstone upland, the escarpment, and the limestone solution plain are examined in detail a great variety of individual karst forms is revealed. All these are closed solution depressions, but they vary widely in area, depth, ground plan, and slope, as well as in pattern of distribution. Some of the depressions are small and steep-sided and have passages opening into underground channels; others are broad and shallow and have bottoms filled with sediment. Some are circular or oval in plan; others are very irregular. The depressions may be widely spaced, with flat uplands between, or they may be so close together that their margins coalesce to form a complicated slope assemblage. Particularly confusing from the standpoint of classification is the intermingling of different forms in the same landscape. In each part of the Kentucky karst, however, there is some dominant form that characterizes the individual area. It is on the basis of these forms that the areal types shown in table 1 are distinguished (figs. 2, 3, and 4).

TABLE 1.—*Karst types*

Type No.	Description ¹	Rock type
1	Cistern sinks on smooth plateau.....	Cypress sandstone.
2	Cave-in depressions in rugged plateau.....	Do.
3	Basins and cistern sinks with knobs and ridges.....	Ste. Genevieve limestone.
4	Doline karst.....	Upper St. Louis limestone.
5	Basin karst.....	Lower St. Louis limestone.
6	Streams and basins.....	Warsaw shaly limestone.

¹ The terms used in the brief descriptions are defined in the discussion of karst types, pp. 8-15.

TYPE 1—CISTERN SINKS ON SMOOTH PLATEAU

On the smooth Cypress Plateau (fig. 4), of which southern Edmonson County is typical, the soluble limestone is overlain by the insoluble, but relatively permeable, Cypress sandstone. Except for a few outcrops in the shallow stream beds, limestone does not appear at the surface. The solid limestone is almost impermeable, but, as this rock is jointed and fissured throughout, surface water seeping through the overlying porous sandstone can continue downward freely through the joints and fissures.

In the beginning the joints were mere cracks, which permitted only very small quantities of water to seep downward, but as time passed the joints were enlarged by solution and the downward movement of water was accelerated until underground drainage became established (fig. 5). As the fissures in the limestone were enlarged, appreciable quantities of the overlying sandstone caved downward.

disintegrated, and were carried away. In this way the underground channels, beginning in the limestone, enlarged upward through the insoluble sandstone to the surface and formed cistern sinks (10, p. 711).

The cistern sink is the first type of karst form to make its appearance (fig. 6), and is most commonly located in the bed of a rill or

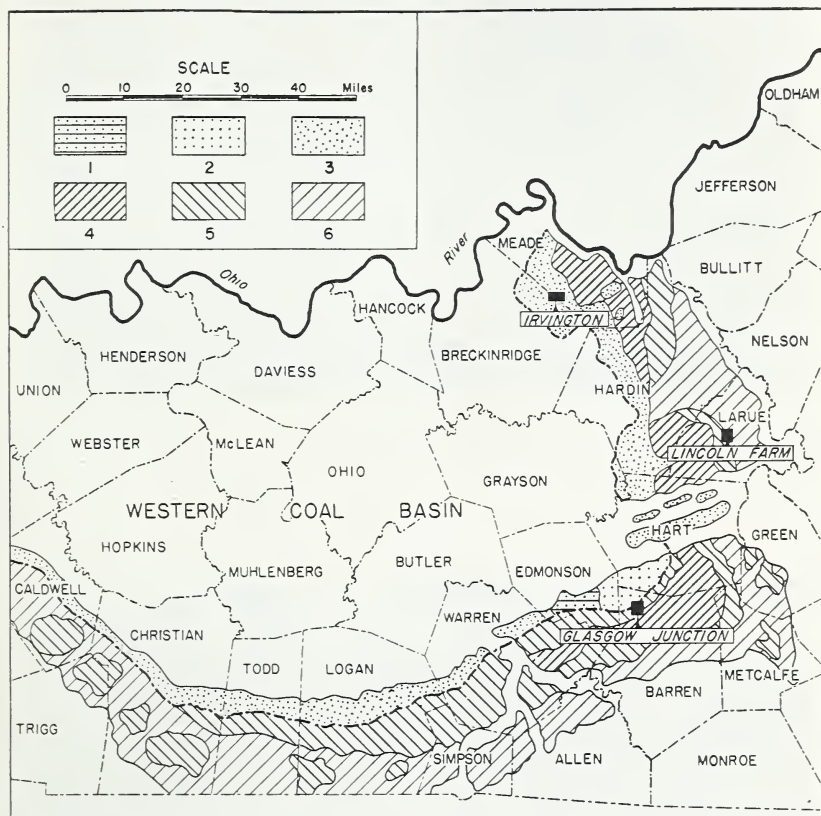


FIGURE 4.—Map of karst types in western Kentucky: 1, Cistern sinks on smooth plateau; 2, cave-in depressions in rugged plateau; 3, ridges, basins, and cistern sinks; 4, doline karst; 5, basin karst; 6, streams and basins. The heavy broken line near the inner margin of the crescent shows the approximate location of the Dripping Spring escarpment. The solid black rectangles indicate areas selected for intensive study, Lincoln farm, Irvington, and Glasgow Junction. (Modified from a map in the *Journal of Geology* (10, fig. 8)).

small stream. When a fissure is opened beneath a stream, part or all of the run-off passes downward to the underground channel. After several such fissures open the entire stream is captured by the underground drainage and the surface water flows only to the nearest sink. The openings of fissures may be temporarily filled with sediment. Even so, water filters through slowly and gradually enlarges the underground channels. In time the sediment is washed on down through the channels, the opening is cleared, and a cistern sink is established. In form, cistern sinks vary from well-like pits, 3 to 4 feet in diameter, with nearly vertical walls, to irregular gully-



FIGURE 5.—Limestone bedrock and the overlying soil in a fresh road cut, 4 miles south of Monticello, Wayne County. Most of the soil was removed by erosion before the road was constructed. Note the fissures in the limestone partly filled with soil.



FIGURE 6.—A cistern sink in Meade County about 2 miles east of Irvington. The rim of the sink, marked by the dashed line, is about 5 feet in diameter. Although the sink shows a tendency to fill with soil, the bottom is open, exposing limestone. The field has been abandoned for several years. Wild persimmon bushes are growing on the slopes of the sink.

like openings (figs. 6 and 33). Cistern sinks are found in all stages of karst development. They are very common in the bottoms of the larger karst depressions but may be formed at any point where fissures are large enough to allow the sediment to be carried away. As the fissures are oriented along joint planes the sinks often have a linear distribution, a characteristic which is passed on to the more mature karst forms.

TYPE 2—CAVE-IN DEPRESSIONS IN RUGGED PLATEAU

In Edmonson, Barren, and Hart Counties a different type of landscape has developed on the Cypress sandstone. Associated with the numerous large caves are the cave-in depressions that are found in the deeply entrenched valleys of the Cypress Plateau. The bottoms of the deepest depressions are in some places 250 feet below the general level of the plateau remnants, which is about 850 feet above sea level. In general the relief pattern is simple; the sandstone uplands are remnant knobs, ridges, or small flats between which lie the valleys originally occupied by surface streams long since captured by the underground drainage. Cave-in depressions in the bottoms of these old valleys have been formed largely by the collapse of the roofs of caves. These depressions are commonly one-half mile or more in width, irregular in plan, and elongate in the direction of the old stream channels.

Ste. Genevieve limestone underlies the lower slopes of the cave-in depressions but it is usually covered with debris from the sandstones above. The areal extent of large cave-in depressions is comparatively small, but similar slopes on the Dripping Spring escarpment are found throughout the entire length of the karst crescent. The soil on these slopes is buff, light in texture, and low in productivity, except on freshly cleared land. (See discussion of the Glasgow Junction area, pp. 33-47.)

TYPE 3—RIDGES, BASINS, AND CISTERN SINKS

Along most of the inner margin of the karst the landscape consists of more or less isolated ridges and knobs, surrounded by lowlands in which broad basins and cistern sinks have replaced stream courses. This type of karst occupies essentially the irregular belt between the heads of the deeper indentations or embayments in the Dripping Spring escarpment and the ends of the spurs and outlying remnants. The escarpment itself cannot readily be mapped as a single line but might be shown more accurately as a zone extending the full width of this third karst type. The position of the most prominent or steepest part of the escarpment differs in different parts of the area. On the southern side of the Western Coal Basin the main break is on the outside of the type 3 karst (fig. 4). On the northeast side of the basin, however, the major break is on the inside edge of the karst crescent.

Viewed from a distance, this third type of karst appears as a normal ridge and valley landscape and only on close inspection are the karst forms and the absence of surface streams noted. Many of the ridges are capped with sandstone, and from their crests long slopes, dotted with cistern sinks, lead down to the former stream

valleys. At the lower elevations there are many closed basins, broad and concave, their bottoms filled with sediment from the adjacent slopes. Since caves are rare beneath the basins and since the presence of numerous cistern sinks indicates that the fissures in the limestone are narrow, it may be assumed that the underground channels are small and are overloaded with sediment. It is evident, however, that vigorous solution is just beginning. As the burden of insoluble sediment supplied by the sandstone is removed, more mature karst forms will develop.

TYPE 4—DOLINE⁵ KARST

Doline karst is developed where solution reaches its highest effectiveness and where the underground channels are able to remove the insoluble sediment. One large area of dolines extends from Warren County to Hart County (fig. 4), a second reaches from northern Hart to middle Hardin, and a third includes western Hardin and part of Meade County. There are other smaller areas, especially near the through-flowing streams, where the karst-making processes frequently are most active because of the easy outlets afforded the underground channels.

Dolines are so varied in form (fig. 3) that they are difficult to define in terms of size, shape, or steepness of slope. They are more symmetrical than the cistern sinks, the slopes may be as steep as 35 percent, and the bottoms may be either open or closed. Simple dolines in Kentucky are round or oval in plan, with diameters rarely exceeding 400 feet. The development of dolines depends on the presence of well-opened underground fissures. If, as is commonly the case, the surface openings are round or irregular but not markedly elongate, the resulting dolines are roughly circular in plan. If the fissures are long and narrow and have several outlets the dolines formed will be essentially oval. The rate of solution is greatest near the fissure, and there the surface is lowered most rapidly. Solution rates decrease toward the periphery of dolines, and the resulting slopes are characteristically convex, being steepest near the bottom of the depression. Similar convex profiles may develop on any surface where the base of erosion, as represented by the bed of a stream, is being lowered more rapidly than the surrounding slopes (23, p. 101).

To summarize, the dolines have the following distinguishing characteristics: (1) Convexity of slope—the doline resembles the bell of a trumpet rather than a funnel; (2) small, flat bottoms intersecting the adjacent slopes in a sharp angle; and (3) approximate symmetry of slope and plan.

The surface of the doline karst is a rolling plain with the highest points lying at approximately uniform elevation, but with the depression bottoms at various levels. An isolated, simple, doline usually is symmetrical, but in the doline karst the depressions are closely spaced and the rims of many of the adjoining dolines and basins intersect, so that most of the depressions are of compound or multiple form (fig. 7). Between the dolines there are irregular domelike hill-

⁵ There is no satisfactory local term for this karst form. Consequently the Slovene term "doline," commonly used in various European and American karst studies (19, v. 2, p. 652), is employed.



FIGURE 7.—Two dolines with intersecting rims, one-half mile south of Lincoln farm, Larue County. The floors, outlined by dashed lines, are covered with fine soil washed from the surrounding slopes. The steeper slopes have not been cultivated for several years, having lost most of the A horizon.

locks, with little evidence of solution other than the absence of normal stream channels or rills. On the doline slopes there are small benches or channelless depressions, dalelike forms which may represent the beginning of subsidiary dolines.

In the bottoms of some dolines are cistern sinks, through which surface water can be discharged quickly. It is probable that open sinks were common before the area was settled, but since the beginning of cultivation of the slopes many of the fissures have become so blocked with erosional debris that they can absorb water only by infiltration. The normal surface soil is a brown clay loam, which when cultivated readily washes into the doline bottoms. Sampling the filled portion of the bottoms often reveals 15 to 20 feet of this topsoil. This rich alluvium makes the depression floors the most fertile spots in the field. (See discussion of the Lincoln farm area, pp. 17-25.)

TYPE 5—BASIN KARST

As degradation of the karst surface continues, a less soluble bed is finally reached. The bottoms of the depressions fill with sediment as the slopes are reduced, and basins are formed (fig. 3). The resulting landscape is the smoothest portion of the Kentucky karst, stretching as far as the eye can see as a gently rolling plain, with the shallow concave depressions lying only a few feet below the general level (fig. 8). Normally the basins indicate a final stage in the karst development. Before the land was disturbed by cultivation they were numerous only on the southern and eastern margins of the karst area, and possibly immediately below the Dripping Spring escarpment. Today basins are widely distributed and are more common than dolines.



FIGURE 8.—A basin west of Fairview, Christian County. The marginal slopes, though gentle, are badly gullied and are no longer fit for cultivation. A part of the basin bottom is producing a good crop of tobacco.

Basins are formed where the fissures underlying a depression are no longer able to carry away the normal amount of incoming insoluble material. This may result from blockage, as of the outlet of a doline, or from the retardation of the solution process where relatively impermeable and insoluble rock lies close below the surface. Blockage of an outlet may be only temporary. The insoluble material may be washed out by an exceptional flow of water or the fissures may be enlarged and reopened by solution, restoring the doline profile. Eventually, however, the depression will be filled and surface drainage will be reestablished. On the lower levels of the St. Louis limestone, basins are the dominant land forms, not because of choking of fissures but because fissures are only poorly developed in the underlying Warsaw formation. Although basins are normally found on the outer margin of the karst crescent they are also the dominant land form on the inner margin west of Warren County (fig. 4). The lower solubility of the limestones and the slightly lower elevation of the land with respect to the through-flowing streams probably prevent the widespread development of dolines.

TYPE 6—STREAMS AND BASINS

The basin type of landscape foreshadows the end of the karst. The bottoms of the basins gradually fill with insoluble sediment, and the rims are lowered by erosion. Both processes are accelerated by soil erosion resulting from unwise cultivation of the land. As the relief decreases the shallow basins fill with water from the heavy rains; water begins to flow from one basin to another, and short, intermittent, surface streams are formed, which later unite to develop a system of surface drainage. Thus the stream-basin type of karst is established with the form of the old basins essentially preserved,

but with surface drainage restored. As stream courses become more prominent the last traces of karst forms disappear.

SOIL EROSION IN THE KARST

The extent of soil erosion varies in different parts of the karst. Some areas have lost only a small part of the topsoil; others have numerous deep gullies in which the bedrock is exposed. The causes of this variance are found in the complex interrelations of climate, bedrock, soil, slope, vegetation, and land use. The climatic factors (31) are fairly uniform throughout the Kentucky karst, except for the influence of local land forms (pp. 39-43). The rainfall is moderately heavy, averaging about 45 inches annually; but of more significance is the fact that the summer rains are often torrential, causing severe erosion in short periods. The character of the soil is less uniform than that of the climate, but the variation within a single rock type is slight. Although the upper part of the soil profile is moderately permeable, the B horizon cannot absorb water quickly, and once the absorbent topsoil is removed, erosion proceeds more rapidly. It is evident that rock, soil, and climate are of fundamental importance in erosion, but the variables that contribute most to the pattern of soil erosion in the karst are the land forms and the activities of man in clearing and cultivating the land. In the following discussions particular attention will be given to differences in erosion in the various types of karst and under changing land use.

A cistern sink is the most common focus of erosion in the early stages of karst development. The breaking of the sod, which exposes lower layers of soil, and the opening of a direct channel to the underground drainage are factors of hazard, whether on the slope of an escarpment or in the floor of a large basin. In either location the formation of the sink may lead to the development of severe gullies, which may eventually extend headward several hundred feet. This hazard is much less evident on the smooth sandstone-capped plateau (type 1), where the abundant sand tends to choke the sink as soon as it is formed. Where cave-in depressions occur on the rugged plateau (type 2) the most severe erosion is found near the bottoms of the long slopes leading down into the depressions. The upper slopes have sandy soils, naturally thin in places, but cultivation has been more general on the lower slopes and they are more severely eroded. In the doline karst (type 4) the soil was originally so thick that bedrock was not exposed at the surface. As a result of more than a century of cultivation, however, the profiles of the dolines have been greatly altered by soil erosion on the slopes and filling of the bottoms. The form of the dolines concentrates the surface drainage on the lower, steeper slopes and results in much damage.

It is probable that before settlement of the karst open cistern sinks were common in the bottoms of the dolines and that through these sinks run-off from the grassy slopes entered the underground channels. Cultivation increased soil erosion, and the fissures became so blocked with sediment that they could absorb water only by infiltration. Some of the dolines were filled to a depth of 15 to 20 feet with topsoil washed from the surrounding slopes. In the basin karst (type 5) the slopes are gentler and longer and there is pro-

portionately less sheet wash and more gullying. Because cistern sinks are present in the floors of many of the basins, large gullies can be formed even on the level basin bottoms. Owing to the underground position of the local base level, the erosion potential is high, and gullies can cut downward and headward from the sink margin with great rapidity. Conditions are similar in the stream and basin areas (type 6), where headward erosion by the newly formed streams is an additional hazard that may lead to gully formation.

Many of the erosion problems in limestone areas are similar to those in areas underlain by insoluble rocks. Others, arising from the underground drainage and the lack of surface streams, are peculiar to the limestone. In both types of areas the increased run-off resulting from cultivation of the land greatly accelerates the rate of sheet wash and gully formation. The intensity of surface run-off is controlled, in part, by the configuration of the lands. In areas of insoluble rock the major drainage lines lie in more or less linear valleys and water may reach the main streams anywhere along either side. In the limestone lands closed depressions take the place of linear valleys and surface run-off converges toward a small bottom outlet, as in a funnel. This produces a marked concentration of the flow on the lower slopes of the solution depressions and subjects them to increased erosion. The washed soil, however, is not necessarily lost from the fields. It may accumulate in the bottoms of the depressions, often leading to stoppage and ponding, but otherwise affording many small spots of exceptional fertility.

The small size of most of the karst land forms is a handicap to the development of effective methods of cultivation and erosion control. Methods of plowing, harrowing, and laying off crop rows suitable to regions of normal surface drainage with broad valley sides, are of doubtful applicability here (5, *p.* 242). Terracing, strip cropping, and other forms of contour cultivation, as ordinarily used, are not easily adapted to the slopes of depressions only 200 feet in diameter. In the karst, fence lines have determined the direction of plowing and planting, with the result that many of the furrows run directly down the slopes and induce gully formation.

SELECTED AREAS FOR INTENSIVE STUDY

From the landscape types found in the Kentucky karst representative areas were selected for special study, to determine in greater detail the variety of erosion factors characteristic of karst lands. In the type areas selected the physical backgrounds of soil erosion differ, and the methods of study were varied accordingly. In the Lincoln farm area the erosion pattern is comparatively simple so that attention could be focused on the degree of erosion in its relation to land form and land use. At Irvington, gullies were given more attention, especially in relation to cistern sinks. At Glasgow Junction, where the karst forms are complicated by the presence of the Dripping Spring escarpment, the problem of exposure, or aspect, was of particular significance. A variant of this type, illustrated by Elk Spring Valley (fig. 1) near Monticello in Wayne County, is briefly discussed. Thus, each area selected was approached from a different point of view in order that the various essential factors of soil erosion in the Kentucky karst might be presented.

LINCOLN FARM AREA

Thomas Lincoln was one of the many settlers who came to the Kentucky barrens at the beginning of the nineteenth century. He selected a farm, now the Lincoln Farm National Park (33), 2 miles south of the site of Hodgenville, Larue County (fig. 4). The immediate attraction was a spring in a cistern sink, which, after a little excavating, yielded a small but steady stream of water. West of the spring now stands a large white oak, which evidently marked one of the boundaries of the farm. It is probably more than 150 years old, judging by its size, but it is the only old tree on the farm. Lincoln's house, in which Abraham Lincoln was born, was built of small logs, and it is probable that there were many small trees growing on or near the farm when it was settled.

Most of the farm lies in the rolling doline type of karst, which has depressions from 10 to 50 feet below the general upland level. Southwest of the farm is a smooth limestone upland with a few intermittent streams and only occasional solution forms. To the north the basin type of karst dominates and there are detached areas of the limestone upland. To the south the doline is the most common land form. The 5 square miles mapped in figures 9, 10, and 12 are fairly representative of the smoother parts of the karst.

HISTORY OF LAND USE

The history of land use in the Lincoln farm area is similar to that of the Kentucky limestone surfaces as a whole. In many ways the land was easy to put under cultivation. The grass could be burned in the spring, and any bushes and small trees easily cleared. Trees were entirely lacking in some parts of this area, and there probably was considerable difficulty in obtaining fuel and building materials. It has been rather generally assumed that this lack of tree growth was caused by the Indian custom of burning the prairie annually, a practice later adopted by the white pioneers on the assumption that it improved grazing (28, p. 128). There appears to be no conclusive proof that the treelessness was the result of burning, and other factors may have played a part. It is reported, however, that with settlement the practice of firing the prairie was abandoned or the wood lots were protected against the burning, and soon there were large areas of woodland on all land not under cultivation (22, p. 83). The dominant growth consisted of several species of oak, and the present wood lots are largely remnants of this post-settlement growth. Although settlement began about 1780 (14, p. 12; 28, p. 135) the land was not well occupied until three decades later, and most of it has been cultivated for only a little more than a century. Corn was a staple crop from the beginning; later wheat and tobacco were added as commercial crops. The predominance of row crops, together with ill-advised methods of plowing and cultivating the karst surfaces, has severely upset the balance between soil formation and wastage. Consequently there has been much erosion and much shifting in cultivation; fields have been abandoned and allowed to grow up in shrubs and briers. Later, as the adjoining lands were exhausted, these same fields were cleared and cultivated again. Accompanying this shift in cultivation there



FIGURE 9.—Land use in the Lincoln farm area in 1936. The major classes of land utilization are shown for about 30 farm units. The intensity of use, excepting woodland, is indicated approximately by the density of the shading. Row crops are not separated, as it is assumed that the erosion hazard of each of these crops is about the same. It will be noted that the largest area of idle land takes the shape of a rude letter Y. Comparison with figure 12 shows that this area has developed the most severe erosion on the slopes of the dolines and basins.



FIGURE 10.—Land use in the Lincoln farm area in 1923, modified from a map by John B. Leighly (28, fig. 84). All land ordinarily cultivated at that time is included under "normal crop land," which corresponds approximately to the row crops, small grain, and hay in figure 9. The farm boundaries, not shown in the original map, are transcribed from figure 9 to facilitate comparison. Note the belt of idle land that extends southward and northwestward from Lincoln Farm National Park in the center of the map. In 1923, as in 1936, the idle land coincides roughly with the areas of most serious erosion.

has been a change in the size and character of the farms. Most of the early farms were large, and many used slave labor. Through inheritance and sale, the size of farms has decreased, the average now being about 100 acres, not only here but throughout the entire Kentucky karst.

A comparison of the map of land use in 1936 (fig. 9) with the similar map for 1923 (fig. 10) shows the shifts in cultivation during the 14-year period. Some land cropped in 1923 is now abandoned, some formerly abandoned is now under cultivation, but a large number of fields have remained out of use during the entire period. Some of the fields in the Lincoln farm area have not been cultivated for more than 25 years, and although bushes and briars have largely covered the scars of soil erosion it is evident that cultivation of these fields is no longer profitable. Much of the abandoned farm land is not severely gullied, but sheet wash, in removing a few inches of topsoil, has reduced the productivity.

At present a large part of the land near Lincoln farm is essentially unused (fig. 9), particularly those areas with well-developed karst forms. Much of this land is covered with bushes and small trees, which by their size indicate the length of the period of disuse. The pasture land is only slightly more productive. Some of it is bushy, but many pastures show signs of recent cultivation. Corn occupies most of the cropped land. Some tobacco is grown, but even where it is cultivated most extensively the acreage is small in comparison with that of corn. The production of small grains, important a few decades ago, has declined in the karst lands as a whole. The woodland is limited to small wood lots on the rougher land, much of which has not been cultivated within the memory of the oldest inhabitants. Some of the oaks are more than 125 years old, as determined by a count of the annual rings, and there is reason to believe that the land on which they stand has never been cultivated. Some of the woodland has well-developed underbrush; some has been partly cleared and used as pasture. Cutting has been done in all wood lots, and therefore no part of the area remains undisturbed by man. The soil profiles in a few places, however, have been modified so slightly that they are practically in a virgin state.

CONTRASTED SOIL AND SLOPE PROFILES⁶

The soil profiles and slopes in the old wood lots contrast sharply with those in the cultivated fields. The steeper doline slopes and the small bottom areas are characteristically wooded. A wood lot containing a doline, only slightly disturbed, lies one-half mile south of Lincoln farm and one-fourth mile west of the Jackson Highway. The higher land surrounding the doline has long been cultivated, and one side of the doline has developed a few shallow gullies. On a portion of the south slope, recently cleared for tobacco, the stumps

⁶As no recent soil survey has been made in the karst lands covered by this circular, and as mapping of the soils of the area was outside the scope of this study, no attempt was made to identify the soils by series and type. The matter was referred to Mark Baldwin, chairman of the Department Committee on Soil and Erosion Surveys, who stated: "There is possibly a correlation with the soils of a similar karst section, part of which was included in the Washington County, Indiana, survey, but our studies are not specific enough to enable us to correlate the soils of these rather widely separated areas. It is not considered advisable nor necessary to undertake to use the system of soil nomenclature of the Bureau of Chemistry and Soils in this publication."

of several large oaks indicate that there has been no cultivation on the slopes of the doline for at least a century. The doline is about 350 feet in diameter and 50 feet deep (fig. 11). From the smooth limestone upland the slopes steepen sharply and are thus definitely convex at the top. The slope increases to about 42 percent near the bottom. From observation of all the woodland areas in the Lincoln farm area, it is apparent that this is about the maximum slope that develops under woodland conditions. Although such slopes are not exceptional in the doline karst, they are rarely under cultivation (30, p. 345).

Few dolines in the vicinity are so little disturbed. There are many, however, of about the same size and plan but shallower and with gentler slopes. One such doline, partly filled, is found about one-half mile east of the one in the wood lot, on the same farm but

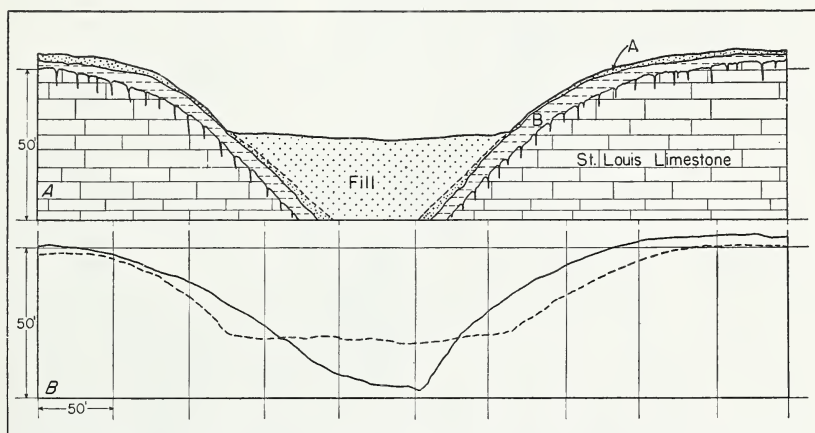


FIGURE 11.—Doline profiles. *A*, A profile section of a doline in a field that has been cultivated for more than a century. The *A* horizon is thin, especially on the steeper slopes. The bottom is filled to a depth of at least 25 feet with soil eroded from the surrounding slopes. The contact of the *B* horizon with the limestone is very irregular and is therefore represented diagrammatically. *B*, The profile of the first doline and the profile of another of similar size in a nearby wood lot. It is not suggested that cultivation and soil erosion have been entirely responsible for the difference in profile, but there is little doubt that the first doline has been filled largely since cultivation began.

in a field that has long been cultivated. The filled bottom is 190 feet in diameter, and the depth of fill is probably more than 25 feet (fig. 11). Sampling with the auger to a depth of 15 feet revealed uniform silt loam, dark gray to black, with one ash-gray layer, probably representing a ponded stage. This bottom fill is derived from the topsoil of the surrounding slopes and, because of selective transportation, is free of rock fragments, except for a few small pebbles. The slopes surrounding the fill have a steepness of about 27 percent near the base and gradually flatten out as they approach the ridges between dolines. The lower portion has been most damaged, owing both to the steepness of the slopes and to the concentration of run-off from above. Most of the *A* horizon has been removed, and the red color of the subsoil is exposed. Apparently most of the damage was done by sheet erosion, but at the present time there are eight well-developed gullies, up to 2 feet in depth, leading



SCALE
0 25 50 75 100 Mile

TYPE OF SURFACE

Limestone Upland Solution Lowland Basin Bottoms

DEGREE OF EROSION

Shallow erosion of A horizon Deep erosion of A horizon A horizon removed; shallow erosion of B horizon A horizon removed; deep erosion of B horizon

Gully

FIGURE 12.—Pattern of soil erosion in the Lincoln farm area. This sketch map of an area of approximately 5 square miles does not represent a complete erosion survey, but shows the characteristic distribution of erosion in this area. The larger areas of limestone upland are little eroded in comparison with the solution lowlands. Erosion is particularly severe around the margins of dolines and basins. Comparison of this map with figure 9 indicates that the areas of greatest erosion correspond approximately to the areas of idle land.

into the filled bottom. It is probable that much soil was removed by rills and small gullies that were repeatedly smoothed out by cultivation.

PATTERN OF EROSION

Erosion is unequally distributed on the various land forms of the karst. If all the dolines and basins were regular in shape and the land use were uniform throughout, the areas of greatest erosion would take the form of circular bands along the steeper slopes. In some parts of the karst this condition is approached and the land as seen from the air assumes a pockmarked appearance. (See front cover.) In general, however, erosion is unequally developed even on the slopes of a single depression. One-half of the depression may be pasture, and the other half plowed land. The field boundaries may be so arranged that one quadrant of the depression may have furrows running up and down the slope and another may have them running nearly on the contour.

The Lincoln farm area, lying in the characteristic rolling doline and basin type of karst, may be used as an example of a typical erosion pattern in the limestone lands of western Kentucky. In the 5 square miles chosen for study it will be noted that the surface may be broadly divided into the smooth limestone upland and the rolling solution lowland (fig. 12), the general level of which is in most places 25 to 50 feet below the upland. Except for sheet stripping, the level limestone upland has been little damaged by erosion. The solution lowland has been much more severely attacked.

The largest area of the solution lowland has the shape of a rude letter Y and is composed chiefly of coalescing dolines and basins. Dolines are more pronounced in the southern part of the area and basins in the north, where there is less distinction between the upland and lowland. Comparison of figures 9 and 12 shows that the greatest area of idle land coincides approximately with this badly eroded solution lowland. The distinction between the upland and lowland both in severity and pattern of erosion is rather strong. Whereas the upland has been fairly uniformly stripped throughout, the lowland has been gashed unequally, depending largely on the use that has been made of the slopes of the dolines and basins. Some parts of the area have been left in woodland for the past century, and these, of course, have lost little soil. Although the solution lowland is now largely classed as idle, a large proportion of it has been under cultivation at some time in the past. The increasing amount of erosion is probably the most important reason for its being thrown out of cultivation.

Within the lowland the degree of erosion varies considerably. Other things being equal, the most severe erosion usually appears on the steeper slopes surrounding the solution depressions. Other factors, probably chiefly land use, have caused variation from this slope control of the erosion pattern. Even so, it may be noted in figure 12 that the badly eroded patches are roughly circular in outline, that the most severe erosion has occurred on the steep slopes that drain into the depression bottoms, and that erosion conditions are worst in the area where dolines predominate, this being the place where the land forms have the steepest slopes. Four degrees of erosion have been indicated (fig. 12).

In a field about 1 mile south of Lincoln farm, in characteristic doline country, convex doline slopes, rounded interdoline ridges, and nearly flat bottoms are the principal elements in the slope assemblage. Several of the dolines have been connected with each other by the process of filing; others are separated by low ridges rising as much as 50 feet above the average level of the bottom. This entire field which contains about 35 acres, has been alternately cultivated and abandoned for more than 100 years.

The various degrees of erosion in the field depend chiefly upon the slope pattern. The only places not eroded are the floors of the dolines, where erosion debris has been accumulating. Next in order are the nearly flat ridge areas, in which more than half of the A horizon usually remains. The upper slopes of the dolines have lost more than half of the A horizon, and the lower slopes all the A horizon and part of the B horizon. The B horizon is so thick that rock exposures are rare even in the gullies.

The soil-erosion pattern is closely related to the surface configuration. The smooth limestone uplands are the least eroded areas, but, although there is little surface evidence of it, the soil profiles even there have been truncated by sheet erosion. Decreased crop yields have been caused by erosion of this type, but the damage is not severe, and the soil would probably respond to proper treatment. Second in the degree of erosion are the gentle slopes of the basins, but they occasionally show serious erosion (fig. 13). The long slopes are subject to both sheet erosion and gullying. As basins are more numerous in the northern half of the Lincoln farm area, erosion is less severe there than on the dolines farther south (fig. 12).



FIGURE 13.—Incipient furrow gullies and sheet wash on a gentle basin slope 1 mile north of Lincoln farm, Larue County.

Flooding and filling of the floors in the basin areas have also been brought about by cultivation. There are no records of ponds in this section when the first settlers arrived; on the contrary, most of the people remarked on the scarcity of water. But ponds, both temporary and permanent, now are numerous, and as a result some of the best land is lost to cultivation. This condition, common throughout the karst, is induced by cultivation of the slopes; the fine soil moves into the basin bottom and renders it impermeable. A few such permanent ponds are useful to the farmer, but basins that are ordinarily dry frequently remain ponded during the growing season long enough to kill the crops.

The doline landscape presents a different erosion pattern. The slopes are shorter and steeper; thus the concentration of surface drainage near the bottom of the depression is more pronounced, and erosion is more severe and more easily recognized. The most severe erosion occurs in circular bands on the steep, lower slopes. The upper slopes are gentle and are less seriously affected by erosion. The partly filled floors are basins of accumulation. Much soil loss is undoubtedly caused by poor methods of cultivation, and even the steepest doline slopes will show little erosion if the soil is in good tilth and if the plow furrows follow the contours.

The pattern of soil erosion found on the dolines and basins in the Lincoln farm area is common throughout the Kentucky limestone section. There are, of course, many variations even in similar types of karst. In the doline karst, erosion is most severe in Meade, southwestern Larue, and northern Hart Counties (fig. 4). In southern Hart and Barren Counties erosion on the dolines is generally less severe, although there are many steep slopes. Erosion varies with soil type, and there is evidently less hazard on cherty soils than where the topsoil is slightly sandy. There is also a clear correlation between erosion and the type of farming. The prosperous farms with good buildings and fences seldom show evidence of severe erosion, a fact which suggests that profitable farming and erosion control are closely related.

In the basin areas the damage from sheet erosion is not so great owing to the gentler gradients, but there is danger of gullying on the longer slopes. In the western part of the Kentucky karst the basin areas are usually in very good condition—the basins are shallow, gullies are rare, and sheet wash is not serious. There are, however, a few exceptions, especially near the Dripping Spring escarpment, where the soils are likely to be somewhat sandy and wash easily. In the vicinity of Fairview, in Todd and Christian Counties, gullying is severe on basin slopes (fig. 8).

The rolling doline and basin land of the Lincoln farm area and similar areas is better-than-average farm land. A few farmers have demonstrated that with care it can be made continuously productive. Thousands of others have shown that careless cultivation leads to destruction. Since settlement much of the land has been slowly decreasing in productivity as a result of erosion. Solution in the underlying limestone has created an erosion hazard far greater than the gently rolling surface might suggest.

IRVINGTON AREA

The Irvington area is situated in the ridge and basin karst (type 3, fig. 4) on the border of Meade and Breckinridge Counties, 1 mile east of Irvington. Although there are no surface streams, the landscape resembles the ridge and valley pattern characteristic of some regions of surface drainage. The ridges and knobs, the most conspicuous features of the landscape, are capped with sandstone as is the upland to the west. Some are flat-topped, mesalike remnants, and others are rounded on top and are known locally as hogback hills. Between the knobs and ridges there are broad valleys, which now have underground drainage. Numerous cistern sinks and partly filled basins have been formed in the bottoms of the old valleys, and the only traces of the former stream courses are near the head-water divides.

The major land forms of the area include the ridge tops, some with and some without sandstone capping; the long ridge slopes below the sandstone, modified by solution; and the transformed old valley bottoms. The ridge tops range from low, rounded, elongate knolls without sandstone capping to long, rounded hills with considerable area on their summits. Some of the tops are large enough for small farms, but most of them are parts of larger valley farms. Many summits that are now wooded show signs of former cultivation. The soil is very sandy and usually includes large fragments of sandstone. Although gullies are not common on the level uplands, cultivation has evidently been accompanied by sheet wash. The long slopes, underlain by limestone, and generally ranging up to 30 percent in steepness, have a high erosion risk. Owing to the length of slope and the widespread distribution of cistern sinks, gullies are formed very readily. It is on these long slopes that gullies are most numerous, but they are neither so wide nor so deep as those on the basin floors.

The most common smaller land forms are the cistern sinks and basins. Generally speaking, the basins are found only in the old valley floors, whereas cistern sinks are everywhere except on ridge tops and reach their greatest development in the knob and basin type of karst. A single field of 20 acres may have 200 or more of these small openings (fig. 14). Many are small enough for the plow to pass over easily. Others, 3 to 4 feet in diameter, with nearly vertical walls, are obstacles to cultivation and to the pasturing of livestock and often become foci for gullying. In a more advanced stage the sides of the sinks will have slumped or washed down, and the tendency to form dolines will be clearly indicated. Many sinks remain open despite filling caused by plowing, by the trampling of animals, and by slumping. Immature dolines sometimes develop from cistern sinks, and occasionally basins have a tendency toward convex slopes on their outer margins, but well-developed dolines are lacking in this area.

Although the basins resemble those in the Lincoln farm area, they are usually larger (fig. 14). Most of them show signs of recent filling, just as the slopes indicate recent erosion. The basins, although receiving the sediment from the slopes, are themselves subject to erosion and wastage wherever a sink is opened in their bottoms.

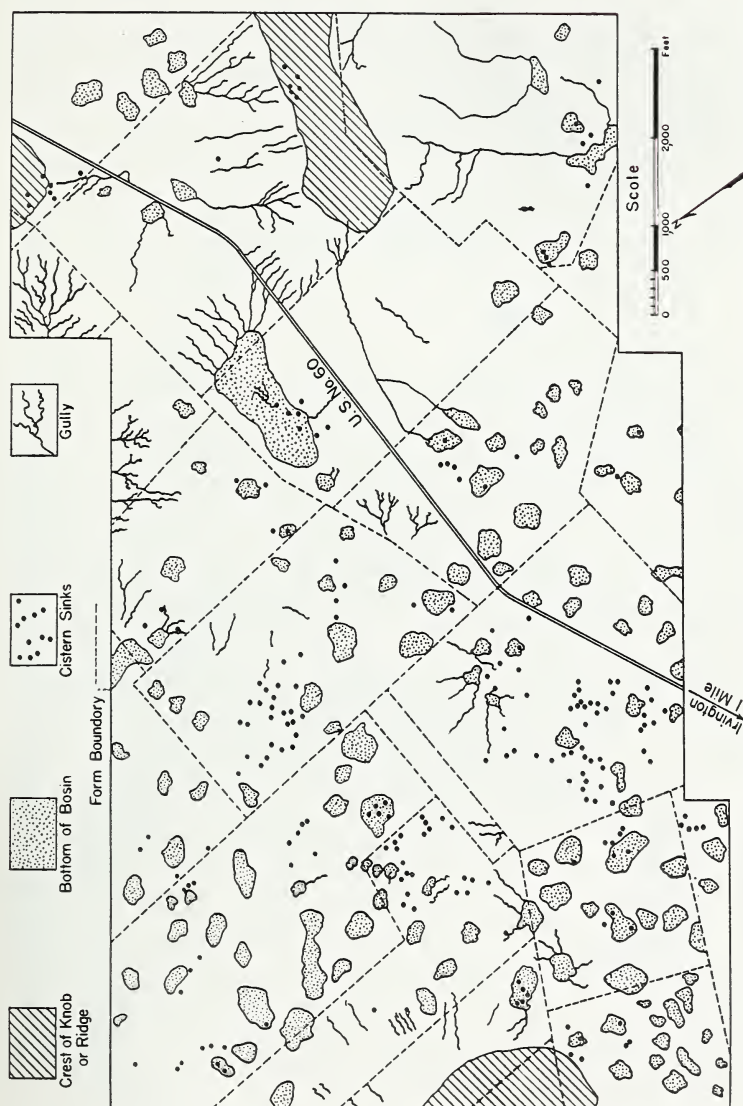


FIGURE 14.—Physical map of the Irvington area showing the distribution of the principal erosion forms. The knobs are low and rather widely spaced. In the broad lowland between the knobs, the cistern sink and the basin are the dominant forms. Only the larger gullies are shown; many others, tributary to the sinks, are too small to be indicated on this map. Compare with figure 15 and note that most of the severely gullied areas are now in pasture.

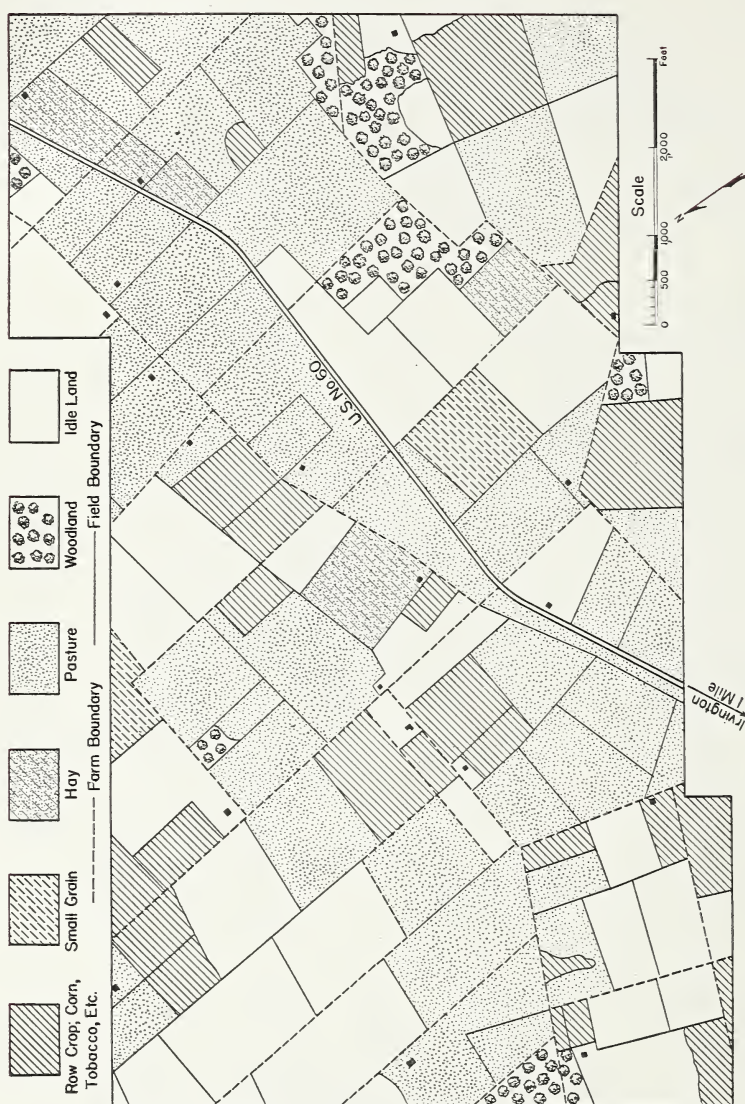


FIGURE 15.—Land use in the Irvington area, 1936. There is much more pasture and less row-crop acreage than in the Lincoln farm area. The idle land is not so conspicuous, as much of the abandoned cropland has been converted into pasture, correlative with a distinct change in farm economy.

FARM TYPES AND LAND USE

The dozen farms that are included wholly or largely in this area were once parts of larger farms (fig. 5). Shortly after settlement most of the land was held by two families. The identity of their plantations has been lost, and even the names of the original owners have disappeared. Through inheritance and sale the average size of farms has been reduced to about 100 acres. When farms were larger the use of the land was less intensive, and the ridge tops and steeper slopes remained in woodland or forest. Practically all of the land shown in figure 15 has been cultivated at some time. Part of the top of Hogback Hill near Irvington shows no evidence of cultivation, but the woodland on the other knobs and ridges consists of small trees, the replacement species, such as cedar, predominating. This would indicate that the woodland has grown up on abandoned land. The proportion of abandoned land in this area, however, is smaller than in many other parts of the karst. (Compare figs. 9 and 15.)

THE ORIGIN OF GULLIES

When run-off is dispersed, there is a tendency toward sheet erosion; when the run-off is concentrated, gullies are likely to be formed. There are several causes of concentration in the Irvington area, some natural and others cultural. One of the more obvious causes is the cistern sink. Sinks themselves are not caused by concentrated surface run-off but by concentrated vertical movement of water. The joints of the limestone where the sinkhole is to form become widened, and, by caving and eluviation, soil enters the underground channels, and a hole is produced at the surface. Caving and washing reduce the slopes of sinks and at the same time increase their horizontal area. On either sloping or level land, gullies may cut outward from the sinks (fig. 16).

All stages in the development of gullies from cistern sinks are to be seen in the Irvington area. There are two rather distinct types, one on the basin floors, where the accumulated alluvium is thick, and the other on the long slopes, where the residual soil is comparatively thin. Before the area was settled it is probable that there were cistern sinks in the bottoms of the old stream valleys. Basins were less numerous. Cultivation of the slopes was accompanied by acceleration of erosion, and large amounts of topsoil were deposited in the lowest parts of the sinks, producing basinlike floors. Cistern sinks and gullies that have recently developed in these basins often reveal buried soil profiles covered with 5 to 10 feet of stratified alluvium, topsoil washed from the adjacent slopes. Beneath such filled basins the fissures are still being actively enlarged, and new cistern sinks appear. The walls are usually vertical in the early stages, but this condition is temporary. As surface water accumulates on the floors of the basins after heavy rains and drains rapidly into sinks, small gullies are formed, which cut headward (fig. 17) and, becoming broader in their upper portions, remove much valuable soil.

Cistern sinks that develop on hillsides are smaller and more numerous than those in the basin floors, and the gullies tributary to them are likewise smaller and shallower. It is difficult to estimate the importance of sinks in gully formation. Gullies commonly



FIGURE 16.—A general view of a basin landscape near Irvington. The gently rolling surface consists of basins and a number of cistern sinks. In the foreground is a partly healed gully. The cistern sink (indicated by arrow), with a tributary gully, is in a stable condition. These fields, formerly in an advanced stage of erosion, have been improved by a planned crop system and simple gully-control methods.

develop at the upper side of hillside sinks and gradually elongate up the slope. If the sink is small or if the quantity of debris washed into it is large, it may become completely filled and obliterated, so that the gully will cut through the down-slope side of the sink and continue down the hill, incorporating the sink into its drainage pattern. Other gullies in the karst originate by the same causes of gullying that are operative in regions having normal surface drainage. Concentration of surface run-off by fence lines, plow furrows, or cattle trails running in the direction of the slope may be sufficient to start a gully. Highway construction, with the accompanying culverts and lateral drainage ditches, has caused many gullies both above and below the road in the Irvington area.

Gullies are found at all positions on the slopes, but near the crests of the knobs they are usually shallower than on the intermediate slopes or in the floors of the basins. Some of the gully heads are narrow and pointed; others are broader, formed by the merging of a number of small dendritic tributaries. In cross section the gullies are usually V-shaped, but the A horizon characteristically breaks off nearly vertically, and the red clay of the B horizon produces gentler slopes near the bottom. Although the gully bottoms are very narrow, the floors sometimes are flat. Many of the gullies empty into sinkholes. The lower ends of others merge into fans built up of soil washed down the gullies.

By no means are all of the gullies traceable to the causes listed above. Especially on the steeper slopes of the knobs and ridges (fig. 18) many gullies run directly down the steepest pitch of the slope

without regard to sinks, furrows, fences, or roads. If the land is continuously cultivated, the soil becomes packed and the run-off meets little resistance as it courses down the slope. Some of the slope-line gullies in the pasture land are being extended by an unusual process. The sod cover is ordinarily a protection to the soil, allowing water to run over the surface without cutting a gully. Much of the water is readily absorbed by the topsoil, but the B horizon is less pervious, and there is a tendency for water to move down slope at the A-B contact, carrying the finer soil particles with it in a sort of horizontal eluviation. If the slope is broken at some point by a road cut or gully, some of the lower topsoil (A_2) washes out, causing a slight sagging in the overlying sod. Concentration of surface drainage in the channel thus formed may soon break through the protecting sod, and a gully will develop.

The most common type of gully is found on the long slopes of the ridges, and many of this type originate in cistern sinks. The depth ranges from less than 1 foot to about 5 feet. Most of these gullies are cut down into the B horizon, but in only a few of the deeper ones does the bedrock outcrop. Sheet wash has removed part of the topsoil from most of the intergully surfaces, and although overshadowed by the more spectacular process of gullying, this removal of topsoil is an important factor in the reduction of soil fertility. Gullies in the basin floors are less numerous but often are deeper and broader, and since they develop in the most fertile areas they are of more concern to the farmers.

Erosion similar to that in the Irvington area is found along the margin of the Dripping Spring escarpment from the Ohio River in Meade County to northern Hart County (fig. 4) and elsewhere on outlying knobs. The greatest risk is apparently on the long slopes of the knobs and in the vicinity of the cistern sinks. Intelligent conservation practices are necessary if this land is to be kept under cultivation without further serious soil losses. If present practices persist, the decline in productivity will continue.



FIGURE 17.—A cistern sink with tributary gullies on a level basin floor, 1 mile east of Irvington. The farmer has attempted to stop the sink with brush and fragments of limestone.



FIGURE 18.—Vertical airplane photograph of a part of the Irvington area, with contours added. The west side of the wooded knob is severely gullied. In the lowland there are many basins, some of them ponded. There are also many cistern sinks, which appear as small black specks. Shallow gullies are discernible throughout the area. The dark splatches in the lighter shaded fields represent eroded areas on basin slopes; the red subsoil photographs black.

GLASGOW JUNCTION AREA

Because wood and water were lacking in most of the karst lands, a number of early settlements were established on the inner margin along the Dripping Spring escarpment, where there were trees and springs. Some of the most important towns in the area have developed from these marginal settlements. In northwestern Barren County the escarpment is indented by numerous coves and solution valleys, each offering a favorable site for several farms (fig. 19). Back of the escarpment the upland is dissected by old stream valleys that have been captured by the underground drainage. Bordering the escarpment on the outer (southeastern) margin are outlying knobs capped with sandstone, remnants of the plateau that formerly covered the cavernous limestones (21, pp. 199-202). The surface is on the whole the roughest in the Kentucky karst, having the steepest and longest slopes and the greatest soil-erosion problems.

Five of the six major types of karst (pp. 8-15) are represented in the vicinity of Glasgow Junction. The location of the area with respect to types 2, 4, and 5, cave-in depressions in rugged plateau, doline karst, and basin karst, respectively, is indicated on figure 4. Although cistern sinks are not so numerous here as in the Irvington area, chosen as typical of the basins and cistern sinks with knobs and ridges, the area mapped at Glasgow Junction (fig. 20) would most appropriately fall within type 3.⁷ Thus within a very small area, there is a wide variation in type of land surface and a great complexity of erosion problems. The flat tops of the larger knobs and the detached areas of the dissected upland in the vicinity of Glasgow Junction reveal erosion problems similar to those of the cistern sinks on smooth plateau type of karst, of which the only area large enough to be shown on the general map (fig. 4) lies in Edmonson County, a few miles to the west. The only kind of karst not represented is the marginal type 6, streams and basins.

The maps of the Glasgow Junction area (figs. 20 and 26) portray the features of Happy Hollow, a solution valley typical of the many embayments along the Dripping Spring escarpment. The valley, developed in the highly soluble Mammoth Cave limestone, contains no surface stream, a characteristic common to all the valleys in this section. The major drainage is in underground channels. Happy Hollow is, in fact, a closed depression, as is shown by the 660-foot depression contour on the map (fig. 20), and is bordered by high knobs connected by lower ridges. At the south end the ridges are less prominent, and the cove widens out to join the lower lying karst plain, which immediately south of Glasgow Junction is a mature doline surface.

The 660-foot depression contour (fig. 20) may be used to separate the karst lowland of Happy Hollow from the surrounding long, steep slopes. Above this level the long, gently concave slopes grade downward from the nearly vertical sandstone cliffs at the top to slopes of 5 to 8 percent near the base. The average slope is about 25 percent, and the difference in elevation is commonly about 200 feet. The

⁷ The extent of type 3 in the vicinity of Glasgow Junction is, however, too limited to be indicated on the general map (fig. 4).



FIGURE 15.—Topographic map of the vicinity of Glasgow Junction. The northern part of the area shown is type 2 karst, cave-in depressions in the rugged sandstone-capped plateau. Well-developed doline karst (type 4) appears in the southern part of the area. The land intermediate between the two is classed as basin karst (type 5). Glasgow Junction lies near the base of the very irregular Dripping Spring escarpment. Happy Hollow extends northeast from Glasgow Junction. The area outlined by the dotted line is shown in greater detail in figures 20 and 21. Scale, 1:62,500; contour interval, 20 feet. (Reproduction of part of the U. S. Geological Survey Mammoth Cave Quadrangle, Ky.)

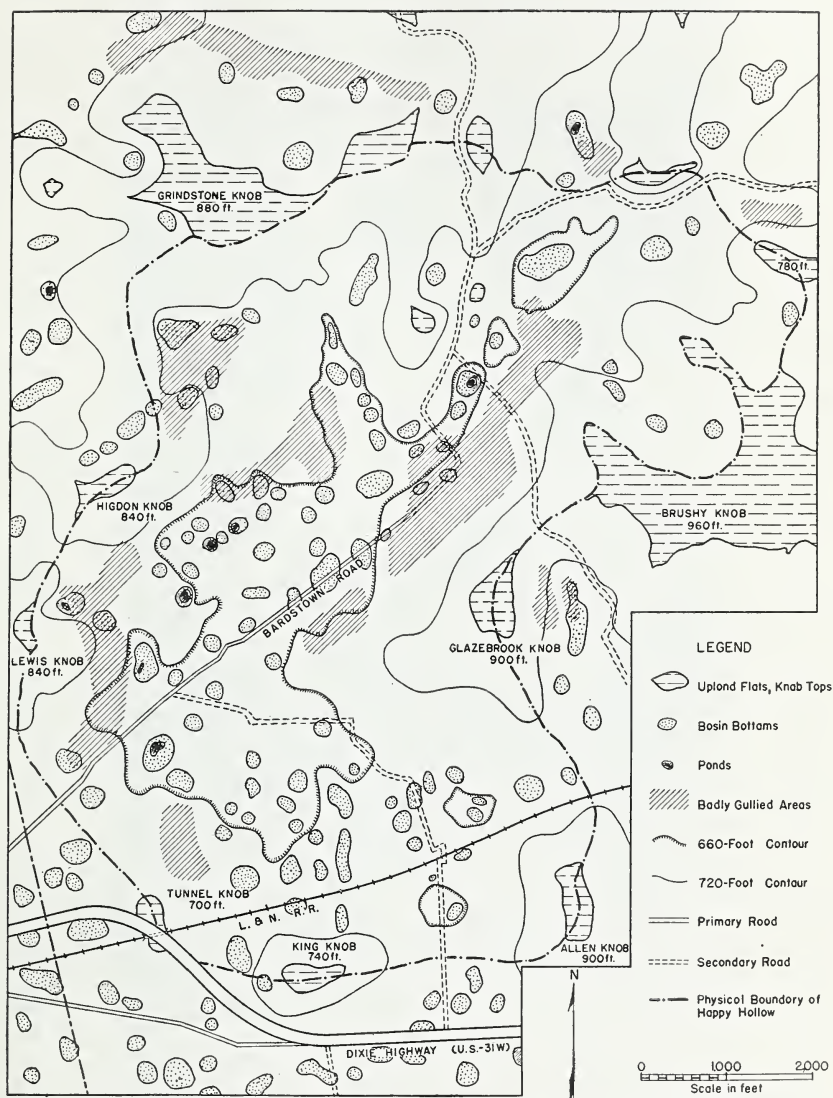


FIGURE 20.—Physical map of the Glasgow Junction area. Happy Hollow is a cove or broad valley invading the sandstone upland, but it has no exterior drainage. The floor of the hollow is a rolling surface composed mostly of basins and intervening low knolls. Bordering Happy Hollow there are knobs and ridges, most of them capped with sandstone, rising 100 to 300 feet above the floor of the hollow. To the north are larger remnants of the sandstone plateau; to the south a well-developed doline landscape.

720-foot contour has been placed on the map (fig. 20) to divide the long slopes into an upper steeper portion and a lower more gently sloping portion.

The rocks in the Glasgow Junction area are essentially flat-lying. There is an almost imperceptible dip of less than 1° to the west. The rock series includes horizontal beds of limestone capped with a layer of sandstone. About 300 feet of the 500-foot thickness of the Mammoth Cave limestone is exposed. This includes the entire Ste. Genevieve section and the upper portion of the St. Louis. The Cypress sandstone caps only the higher knobs, and on some of these it is as much as 75 feet thick.

The lowland parts of the Glasgow Junction area, the part of Happy Hollow lying below the 660-foot contour, for example, include about all that could be called mature karst. All stages in the development of karst forms from the small open cistern sink through the large convex doline to the filled basin may be seen there. Although in Happy Hollow basins are much more common than dolines, this area must be considered to be in a more youthful stage of karst development than the areas of doline karst. Basins have formed directly without the intermediate doline stage, because the sandstone outcropping on the knobs surrounding Happy Hollow has supplied insoluble debris faster than it can be removed through the underground channels. There are some cave-in dolines and many cistern sinks, but they are not so numerous as in the Irvington area. Relatively short and fairly gentle slopes prevail in the broad valley-bottom areas. This undulating land, including the basin floors, is the chief farm land in the area.

In the broad karst plain directly south of Glasgow Junction and Happy Hollow dolines greatly outnumber basins. This surface consists of numerous coalescing dolines, and although the slopes are short there is practically no level land. Fifteen to twenty well-formed dolines can be found in any of several 25-acre fields. Where such a surface has been unwisely cultivated it often has been damaged beyond repair. (Compare figs. 21 and 22.)

Variations in rock type, slope, and exposure account for the existence of several distinct soil units in the Glasgow Junction area. Although each of the soil units can be ascribed to a typical location on the land surface, the profiles of each unit exhibit definite differences in the soil itself. On the flat upland and on the sandstone-capped knobs, the typical soil consists of about 6 inches of brown fine sandy loam underlain by a yellow-brown plastic clay subsoil, 8 to 10 inches thick. The parent material is a loose yellow, red, and gray mottled sand derived from the buff medium-grained Cypress sandstone.

On the low limestone knolls and gentle slopes in the karst lowland, the topsoil is normally a mellow brown silt loam about 12 inches thick. It is underlain by clay that from place to place varies in color from dull brick red, deep blood red, or brilliant orange scarlet, to dark chocolate. Differences in apparent color and structure are often dependent on variations in moisture and light conditions, for the profile may be different in appearance when observed on successive days. The red clay makes a sharp contact with the solid but highly fissured underlying bedrock, the Mammoth Cave limestone. In places the bleached white limestone extends to the



FIGURE 21.—Aerial photograph of the Glasgow Junction area, showing Happy Hollow and a portion of the karst plain. The village of Glasgow Junction is at the lower left. The dark, circular splotches, especially common in the lower third of the view, are doline depressions. Doline topography is still better developed farther south and west, as shown in figures 19 and 22. The northern two-thirds of the area is more rugged, and the wooded knobs contrast sharply with the cultivated hollows. Thin cedar glade woodland, through which may be seen exposures of gray limestone, occupies many of the knobs. Farm boundaries and the outline of Happy Hollow have been inked in for easy comparison with figures 20 and 26.

surface. Elsewhere it is covered by as much as 20 feet of the red clay. The bleached effect shown by the exposed rock usually is caused by a very thin film of a white alteration product covering the entire surface of a blue, gray, or pink limestone, but the lack of more than a fraction of an inch of an intermediate alteration zone between the rock and the red clay is characteristic. The abruptness of this contact between the red clay, blocky when dry, plastic when wet, and the solid impervious limestone base is significant in the erodibility of these limestone soils. Where the bedrock is the St. Louis limestone, chert fragments are common throughout the soil and on the ground surface. By serving as a sort of filter, the abundant chert probably reduces the amount of erosion that would occur in these soils were the chert not present. The lack of so much chert in soils of similar type overlying the purer Ste. Genevieve limestones may partly account for the more severely eroded conditions of the Ste. Genevieve soils. In the Glasgow Junction area, however, the fact that the soils derived from the Ste. Genevieve are usually found on the steeper slopes is probably a more significant factor. Except for having less chert, the subsoil is a red clay similar to that in soils derived from the St. Louis limestone. There are occasional chert fragments and in places a considerable number of small, honey-combed, silicious pebbles. The topsoil is usually a brown fine sandy loam averaging about 6 inches in thickness.

Soils on steep slopes differ according to the position on the slope. In the upper reaches of the limestone slopes, just below the sandstone outcrops, the texture of the A horizon is particularly coarse, owing to the presence of grains weathered from the sandstone. Sandy loams are common on the upper slopes even on limestone knobs that, although formerly covered, no longer have a sandstone cap. Yellow is more prominent in the subsoil of the upper slopes than of the lower reaches, where red predominates.

On the long slopes, soils of even the same limestone horizons differ greatly according to the direction in which the slope faces. Deep soils characterize the north-facing slopes and very thin soils the south-facing slopes (fig. 23). Large expanses that are practically devoid of soil, other than that remaining in limestone fissures, are common on south-facing hillsides (fig. 25). The same flat-lying bed of limestone that on the south-facing side of a knob may be covered only with a thin film of sandy topsoil material, an inch or so thick, may on the north-facing side of a knob have an A horizon over a foot in thickness. The subsoil similarly varies with the direction of exposure, or aspect. Not only is it thinner on south-facing slopes, but it is also yellower and more plastic. The soils of the east-facing and west-facing slopes are intermediate in regard to these characteristics.

The soils of the basin floors are accumulations of wash from the surrounding slopes. In most cases there has not been sufficient time for the profile to differentiate into horizons. Many basins have been filled to a depth of several feet within the last century, the period during which the surrounding slopes have been disturbed by cultivation. This fill is typically a reddish-brown sandy loam—a mixture of the sand, silt, and clay of the normal mature soils of the adjacent lands.





FIGURE 22.—Aerial photograph of a typical doline landscape near Rocky Hill, 5 miles southwest of Glasgow Junction. The area seen in this view has been inhabited for a long time, and judging from the numerous gullies that appear on the short but steep slopes it has been cultivated with little regard to conservation of the soil.

Borings in many of the basins have revealed the existence of a dark layer, rich in organic matter, often lying several feet below what may be assumed to be fill resulting from culturally accelerated erosion. This layer may be correlated with a similar surface layer on wooded slopes that have never been cleared. Brown loam is the topsoil most frequently seen in old cleared areas, but in recently cleared fields dark-gray sandy loam surface soils remain, suggesting that the dark layer originally extended from the knob tops to the basin bottoms.

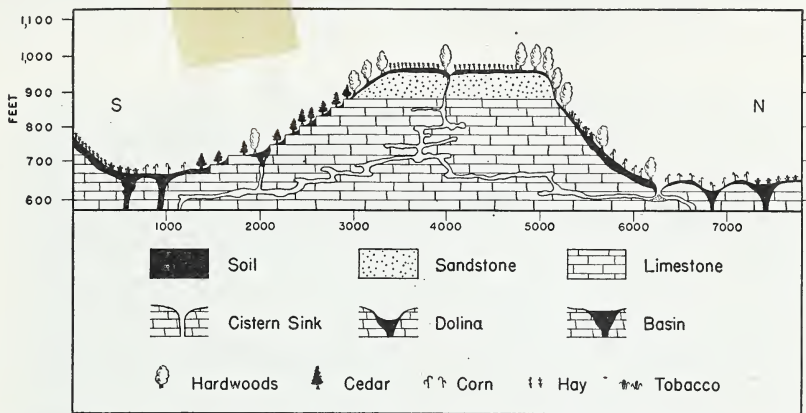


FIGURE 23.—Profile section of Brushy Knob, which borders Happy Hollow on the east, rising about 300 feet above it. The south slope has well-developed cedar glades and numerous outcrops of limestone. The north slope has hardwoods, thicker soils, and some cultivation. The solution channel, filled with soil, and the open underground channels are diagrammatic. The vertical scale is about four times the horizontal.

VEGETATION AN EXPRESSION OF EXPOSURE

The first settlers in the Glasgow Junction area found three types of vegetation: Grassland in the broad valley; oak-chestnut forests on the north-facing slopes and the tops of the knobs; and cedar glades on the steep, south-facing limestone slopes. The grasslands, known to the settlers as barrens, extended into the rolling basin land of Happy Hollow and other similar coves and became the most important farming land. Subsequent cultivation has prevented the growth of trees except along the fence rows and roads and in a few wood lots. In such places oak, hickory, and cedar have reached large size. The climax oak-chestnut forest, found on most slopes and on the tops of the ridges, included many species of hardwood, but oaks predominated. Chestnut was common on the ridge tops, and maple, elm, sycamore, and beech were intermingled with the oaks on the lower slopes. The floristic composition was much more varied than that in the forests that have developed in the barrens since the beginning of settlement. Several fairly large areas of woodland remain on the steep slopes of the larger knobs and on some of the smaller knobs that, owing to their rounded tops, thin soil, and insufficient level land for crops, have not been cultivated.

The cedar glade is the most distinctive vegetative type within the area (fig. 24). Its typical location is on the steep, south-facing lime-

stone slopes, where the soil is extremely thin or does not even cover the fissured bedrock. Most of the soil is in the fissures, and large limestone blocks often protrude 5 to 6 feet above the surface. Vegetation which can grow successfully under these conditions is limited chiefly to red cedar, scrub oak (mostly blackjack), and bluestem (*Andropogon virginicus*), locally called broomsedge. In some places the vegetation forms a parklike landscape, and in others there is a continuous cover of scrubby trees.

When viewed from a distance the cedar areas are distinguishable by their darker color and appear as horizontal strips on the south-facing slopes of knobs and of depressions such as coves and large



FIGURE 24.—View of a cedar glade across a cave-in depression in the sandstone upland, looking north. The cornfield is in the basin bottom, where the best soil is found. The gentler lower portion of the south-facing slope has been cultivated recently and has a few shallow gullies and signs of moderate sheet wash. The upper slope with the dark cedars showing is so severely eroded that limestone shows through the trees. Whether this upper slope was ever cultivated is debatable. The cedar trees are 60 to 75 years old, and there are numerous clifflike ledges of limestone but very little soil.

dolines. On closer examination, the outcrops of bleached, white limestone become conspicuous. The upper limit of cedar growth follows the line of contact between the sandstone and limestone. Above this the cedar glades merge into the oak-chestnut forest. In the lower reaches the glades gradually lose their identity as the slopes become gentler and the soil cover thicker.

Cedar glades form a striking contrast to the characteristic vegetation on slopes that face the north. In a cove with an east-west alignment, for example, the northward-facing slope is mantled with deep soil and supports a dense oak-chestnut forest, whereas the southward-facing slope is covered with a scattered growth of cedars, blackjack, and broomsedge growing on the thin soil between the limestone outcrops (fig. 25). This contrast exists even where the northward-facing slopes are much steeper than those facing south. Where the towering

hardwoods (including red, black, white, and chestnut oaks, hickory, maple, and many other species) have been cut off and replaced by cultivated fields the contrast is even sharper. The north slopes are generally very fertile and are often cleared and cultivated in spite of their steepness. The cedar glades of the south slopes, however, are rarely cleared.

These contrasts in vegetation reflect fundamental differences in soil (fig. 25) and local climate. Both are attributable to differences in the angle at which the sun's rays strike the ground surface on contrasting slopes. Northward-facing slopes receive sunlight at a lower angle of incidence and for a shorter length of time daily than do slopes that face the south. There are many days when northward



FIGURE 25.—Slopes on opposite sides of a cove aligned in an east-west direction. The south-facing slope in the foreground is characterized by extremely thin soil and scanty vegetation; the north-facing slope in the background, by much deeper soils and, where uncleared, by dense vegetation.

slopes are protected by a cover of snow or frozen soil. The sunny southward slopes, on the contrary, are thawed frequently and thus are subjected to the erosive action of running water and to mass movement (26; 27, p. 42). The increased protection afforded by snow and ice on north-facing slopes often lasts for long periods during the winter.

The percentages of insolation on north-facing and south-facing slopes at latitude 37° N. are indicated in table 2, the intensity of solar energy received at noon on surfaces perpendicular to the sun's rays being assumed to be 100. These values do not take into account the length of day, the atmospheric conditions, or the variations in the solar constant, as these affect both slopes equally. The sun would shine for a slightly longer period on the south-facing slope in winter and on the north-facing slope in summer, but this has little effect on the relative total amounts of insolation.

TABLE 2.—*Insolation on north-facing and south-facing slopes of various angles at latitude 37° N. at the time of the solstices*¹

Date and slope direction	Insolation on slopes of—				Date and slope direction	Insolation on slopes of—			
	0°	10°	20°	30°		0°	10°	20°	30°
Dec. 21:	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	June 22:	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>
North-facing slope--	48	33	16	0	North-facing slope--	97	91	84	72
South-facing slope--	48	64	76	86	South-facing slope--	97	99	99	96

¹ The maximum insolation, 100 percent, can be received only on surfaces that are perpendicular to the sun's rays.

Tables have been prepared that show the number of freeze-thaw alternations experienced in a year throughout the United States.⁸ These indicate that central Kentucky lies in approximately the middle of the zone that experiences the greatest annual number of alternations. From 40 to 70 alternations may be expected in any one year. The frequency decreases both to the north, where the land is frozen more of the time, and to the south, where the ground remains thawed for longer periods. The repeated heaving of the soil during periods of alternate freezing and thawing renders it susceptible to washing and aids in moving the soil mass gradually downhill. This process is especially significant on south-facing slopes because it is on southern exposures that the greatest number of diurnal thaws are experienced. On many days when the temperature is near 32° F. (common in this latitude in winter), the southward slopes will thaw out under the heat of the more direct rays of the sun, whereas the relatively shaded northward slopes will remain frozen and protected. Not only are washing and mass movement active on the southward slopes during the daytime, but when freezing occurs at night the growing ice crystals play their part in loosening the soil particles and preparing the way for them to move down the slopes (29, pp. 28-29).

Frost action is limited to the winter season, but the effect of exposure on evaporation is of year-round significance. Sunny south-facing slopes, receiving more insolation than the shady north-facing slopes, experience greater loss of soil moisture by evaporation, and vegetation on them suffers in consequence. Because of the lack of a protecting vegetal cover, the soil tends to wash more freely. The resulting thinness of the soil on southern exposures is, in turn, reflected in the sparse vegetation.

The physical elements causing greater erosion on south-facing than on north-facing slopes are chiefly climatic. The contrast is expressed in varying degrees of intensity in different parts of the country. It is especially striking in the Glasgow Junction area and along the Dripping Spring escarpment because of local climatic, geologic, and ecologic conditions. The long limestone slopes have a cover of loose soil that can readily be removed from the solid impervious base. In many places the surface consists more of limestone bedrock than of soil, and, as erosion progresses on the south-facing slopes, more and more limestone is exposed.

⁸ RUSSELL, R. J. Letter to junior author, Baton Rouge, La., October 2, 1936.

The close correlation between availability of calcium and abundance of growth of red cedar is well recognized (35, p. 495). Cedar is characteristic of limestone soils, especially where the rock either is exposed or is near the surface. Many of the old glades on south-facing slopes are of presettlement origin, but second-growth glades have developed on badly eroded land, irrespective of exposure. That glades of this type are increasing was noted by Sauer (28, p. 85):

The area of the type [glade] is increasing, as the soil cover is swept from the surface of the limestone to the bottoms of the depressions. This type is characterized by the growth of red cedar (*Juniperus Virginiana*), and the young reproduction of this species is a measure of the progress of the denudation of the limestone surface.

HISTORY OF LAND USE

In 1798 there were only four families in what is now Barren County, and all were living near the present site of Glasgow (12, p. 1), on the eastern margin of the narrowest part of the barrens. The grass-covered strip of barrens, here about 12 miles wide, was unattractive to the pioneers because of its lack of an adequate supply of wood and water. For that reason the next group of settlers to arrive pushed on across the barrens and settled on the opposite side, close to the Dripping Spring escarpment, where the village of Three Forks began to develop.

Most of the early settlers in the vicinity of Glasgow Junction came from Virginia, and in a short time slavery was introduced. Captain Ballenger, one of the first settlers, is reputed to have employed 200 slaves on holdings said to amount to 12,000 acres, occupying the southeastern part of Happy Hollow, southeast of the old Bardstown Road and south of Glazebrook Knob (fig. 20). Before the Civil War exports consisted chiefly of tobacco and livestock. Corn and wheat were raised only for home consumption. Tobacco, cultivated according to methods used in Virginia, was transported to the New Orleans market by way of the Green, Ohio, and Mississippi Rivers. Livestock was driven overland to Louisville.

The Louisville & Nashville Railroad, completed just before the Civil War, passed through Three Forks and afforded a ready outlet for the produce of the area. The name of the settlement was changed to Bell's Tavern, and in 1869, after a branch line was built to Glasgow, the present name, Glasgow Junction, was adopted.

Significant in the history of the Glasgow Junction area since the Civil War has been the breaking up of the large plantations. This was accomplished in part by parceling the holdings to several heirs and in part by the outright sale of smaller areas. Even in the eighties farms were much larger than they are today. At that time the major part of Happy Hollow was in the hands of two owners, Hindman and Poynter. The Hindman place, lying between the Bardstown Road and the Louisville & Nashville Railroad (fig. 26), was a portion of the old Ballenger plantation, bought from one of the heirs. The Poynter place adjoined it on the northwest side of the Bardstown Road. Today five complete farms are situated on the former Hindman holdings, and three occupy the Poynter farm.

History reveals that the climax in the economic development of Happy Hollow occurred at the time of the Hindman-Poynter regime. As a result of the intensive use of the land on these two

superior farms, the introduction of culturally induced erosion, and the subsequent subdivision of the estates, no farm stands out today in marked superiority to the others. In fact, the farm map of today

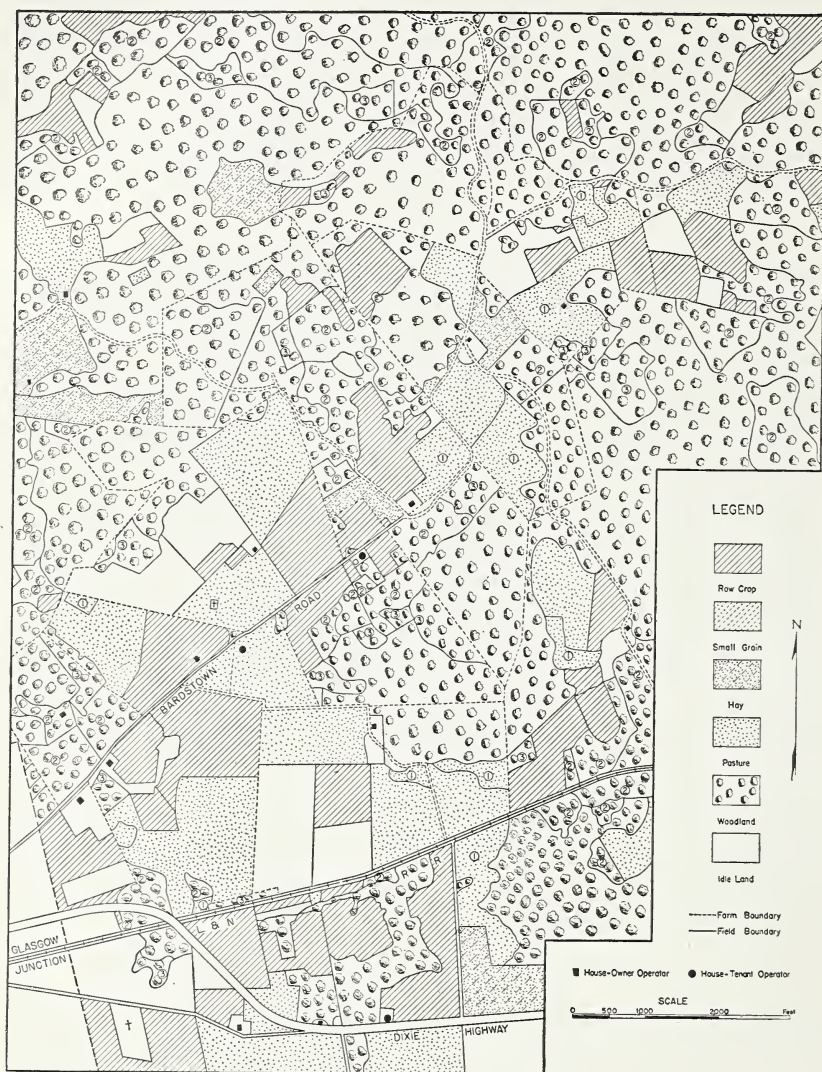


FIGURE 26.—Land use in the Glasgow Junction area. Most of Happy Hollow (fig. 20) is in crop or pasture land, but the surrounding slopes and the ridge crests are largely wooded. Much of the woodland has been cultivated at some time in the past, and various stages in the reversion to forest are expressed by the encircled numbers: ① Brushy pasture; ② low brushy woodland not used for pasture; and ③ more advanced woodland with but few trees of saw timber size. The woodland areas without numbers have been frequently cut over but never cleared.

presents a picture of surprising uniformity in farm conditions (fig. 26). Most of the farms are about 100 acres in size. The largest, 150 acres, includes an exceptionally large amount of old-field acreage; the smallest, between 50 and 60 acres, is the only holding in the

area that is not cultivated, being completely covered with timber, some of which has grown up in recent years as old, eroded fields were abandoned. The other Happy Hollow farms are similar not only in size, but also in land utilization. Corn and tobacco are grown on basin land, and wheat is customarily omitted from the rotation. Most farms have old fields, usually gullied and largely grown up in cedar, which serve together with other woodland areas as farm wood lots.

The cultivation of cotton and wheat is now chiefly a matter of historical record. Cotton was tried as an experiment several years ago, but the climatic handicap proved too great, and the experiment failed. Wheat is still grown to some extent, but the acreage has decreased in recent years. As the Great Plains were opened to wheat, the crop was grown less and less in the Kentucky karst. According to local residents, the decline in the importance of wheat began about 30 years ago.

The acreage of small grain shown on the land-use map of the Glasgow Junction area (fig. 26) is not wholly representative of the Kentucky karst. On the smoother lands (fig. 9) small grains occupy a relatively larger acreage. The absence of wheat in Happy Hollow results in part from the poor roads and the consequent difficulty of getting a threshing machine into the hollow. It will be noted that the two fields of small grain shown on the map (fig. 26), both on the same farm, are located near the Dixie Highway and are thus easily accessible.

The term "row crop" on the map denotes the clean-tilled crops that are most conducive to field erosion—chiefly corn and tobacco and a few patches of sorghum and garden truck. Of the two major row crops, tobacco is considered to be the more conducive to erosion. It requires meticulous cultivation, which keeps the soil stirred up, whereas cornland is commonly laid by early, permitting the growth of weeds and grasses, which serve as a partial protection after the corn is cut.

The customary rotations produce a year-to-year rearrangement of the land used for row crops, small grain, hay, and pasture, as well as that allowed to remain fallow. Consequently, the land-use map (fig. 26) is accurate in detail only for 1936. The detailed presentation of the current land use, however, not only provides a 1936 datum, but also shows the comparative acreage devoted to the different crops. The acreage now in row crops represents about the minimum on which the farmers can subsist. Tobacco supplies a small cash return; garden truck, the household food supply; and corn, the stock feed. It is the common practice to plant enough corn to insure an ample feed supply. If suitable land remains, it is devoted to tobacco.

PATTERN OF EROSION

The various types of land in the Glasgow Junction area have not been cultivated with equal intensity. Some parts of the upland have never been cleared. Others have been successively cleared, cultivated, and abandoned, some of them a number of times (fig. 21). The long slopes have been cultivated more frequently, especially near the bottom, and most of the basin land has been in crop or pasture continuously since settlement. Any explanation of the present erosion

conditions requires an understanding of the past land use as well as the relation of soil erosion to slope and to soil quality. The smoother parts of the uplands have been damaged but little because the slopes are gentle and the sandy soils are porous. Although there are scattered cistern sinks most of them are blocked with sand and do not ordinarily induce gullying. On limestone knobs from which the sandstone capping has been removed, subsoil and bare rock are conspicuous, suggesting that the limestone soils are more susceptible to erosion than those derived from sandstone. The seriousness of soil erosion on the tops of knobs and knolls is obvious when it is considered that there is no possibility of replenishment of the soil from above by slope wash or mass movement, as is the case on lower slopes and in basin bottoms.

Although only portions of the long, steep slopes connecting the sandstone uplands with the limestone lowlands are agriculturally significant today, a study of them is of value for determining principles of erosive action that may be applied to slopes still possessing tillable soil. The length of the slopes is in itself a hazard. Although the upper parts of the slopes are usually steeper, the run-off is more concentrated near the base of the slopes, and gullies are more likely to form there. Gullies 4 to 5 feet deep occasionally terminate in cistern sinks but more commonly fan out either on or just uphill from the basin floors. If these gullies are not checked they broaden out until they resemble elongated galls and may cause the complete destruction of the fields in which they lie.

The effect of exposure has already been discussed. The slopes facing southward are particularly subject to erosion caused by excessive evaporation and by the alternation of freezing and thawing. If the south-facing slopes are unwisely cultivated, the natural erosion processes are aggravated and destruction proceeds rapidly (fig. 27).



FIGURE 27.—Gully formed on a gentle southwest-facing slope by wagon ruts during a period of tenancy. This field formerly produced good crops of corn and tobacco.

These principles are illustrated in the Glasgow Junction area by the prevalence of severe gullying and land abandonment on the lower slopes, chiefly between the 660- and 720-foot contours, and by the existence of thin-soiled cedar glades on south-facing slopes.

ELK SPRING VALLEY AT BARRIER

In the Cumberland River country of south-central Kentucky there is an area of karst land (fig. 1) that differs in two respects from the area already discussed—the soluble limestones are not so thick, and there are numerous through-flowing streams, the Cumberland River and its tributaries. There are a few broad solution plains, but much of the karst is in the valley bottoms formerly occupied by streams. Between the valleys are high ridges, capped with sandstone. The landscape in general is similar to that in the Glasgow Junction area, but the ridges are higher, and are long and narrow. Although there is little level land and there are few large cave-in depressions, this area has the typical characteristics of the escarpment lands, with sandstone cliffs above long limestone slopes. Short tributary coves, similar to Happy Hollow but usually smaller, border the main valleys.

Elk Spring Valley, near Monticello in Wayne County (fig. 1), is typical of the long valleys cut in the sandstone upland, which are now without surface drainage (fig. 28). The original valley floor has been completely modified by solution, the drainage is entirely underground, and the surface consists of numerous basins and dolines with intervening rounded knolls and low ridges. The valley is about 940 feet above sea level, and the ridges, rising 1,300 to 1,400 feet, are irregular remnants of the upland. Many ridges are continuous for several miles, with almost no outlying knobs. At Barrier, 6 miles southeast of Monticello, the valley has an east-west orientation, with a marked contrast between the north and south slopes.

The valley was settled in 1801-2. Before that time it had been a hunting ground of importance, and descriptions of presettlement conditions were handed down by the hunters. The features that most impressed both hunters and early settlers were the springs and the almost impenetrable canebrakes. The fact that there were few stream channels and no running water in the valleys seems to have made little impression. The settlers came from Virginia, and the names of the first families—Coffey, Oattes, and Ingraham—are still present in the valley. Most of the families acquired land by purchase rather than by grant, and the holdings were large, stretching across the valley from ridge to ridge. In the course of time these settlements developed into small plantations employing slave labor. The number of slaves on each plantation is not known today but was not in excess of 50, and was probably much less. There are indications that the land was more intensively cultivated at that time than at present, but this is debatable since there are more people living in the valley today than during the first half of the nineteenth century.

Shortly after the canebrakes on the valley floor were cleared, cultivation spread gradually up the valley sides. Only the lower portions

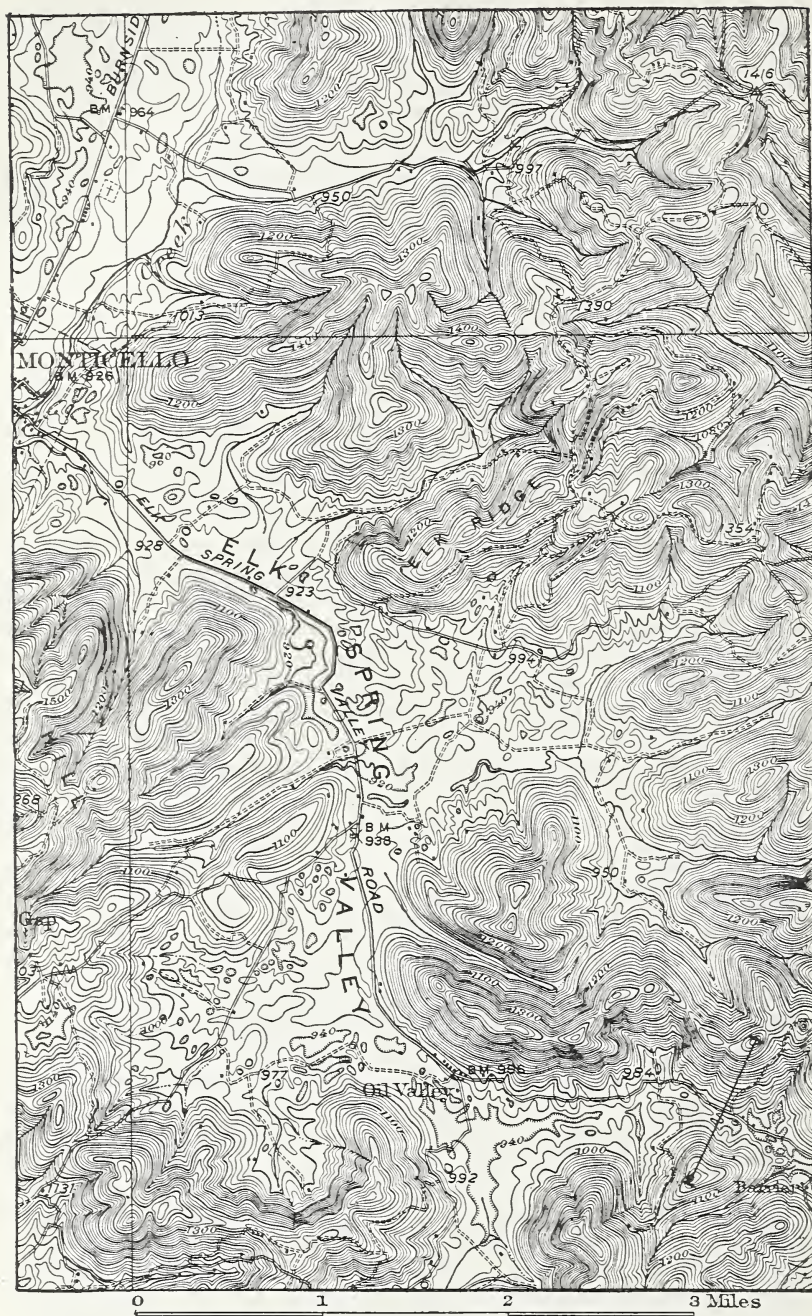


FIGURE 28.—Topographic map of Elk Spring Valley and the adjacent area. Barrier is at the upper end of the valley at the southeast corner of the map. The position of the section (fig. 50) is shown. Scale, 1:62,000; contour interval, 20 feet. (Part of the U. S. Geological Survey, Monticello, Ky., quadrangle.)

of the south-facing slopes were cleared, but clearing of the north-facing slopes was almost complete and has been repeated periodically after temporary abandonment. Most of the slope clearings have been severely eroded (fig. 29), and many are now abandoned. Unlike the areas previously discussed, the country south of the Cumberland did not begin to grow tobacco until very recently. Lack of adequate roads prevented the exportation of farm products until about a decade ago. Today tobacco is grown in many localities, but corn, wheat, and hay are still the most extensive crops.

A section across the valley will indicate the nature of the erosion problems. The profile is slightly asymmetrical in that the southern ridge crest is approximately 100 feet lower than the northern and the southern slope is shorter (figs. 30 and 31). The grade on the two sides, however, is approximately the same, 18 to 20 percent.

The slopes are characterized by numerous rock benches, which are essentially flat or slope gently toward the valley, but in rare instances slope away from it. Between the benches the hillside slopes as steeply as 25 to 35 percent. Solution forms, resembling those of the valley floor, are present on many of the benches, especially those that slope toward the hill. Small dolines, for example, have been formed even on the higher limestone slopes.

In the profile (fig. 30) are shown the 11 recognized types of surface, which are distributed in parallel bands following the contour of the valley. These result from the major variations in physical conditions and land use, and together form a representative cross section of Elk Spring Valley. The 11 types of surface are described in order, beginning on the southern ridge crest and proceeding northward.

1. The southern ridge crest, capped with sandstone, has been logged but not cultivated and appears to have been little affected by human

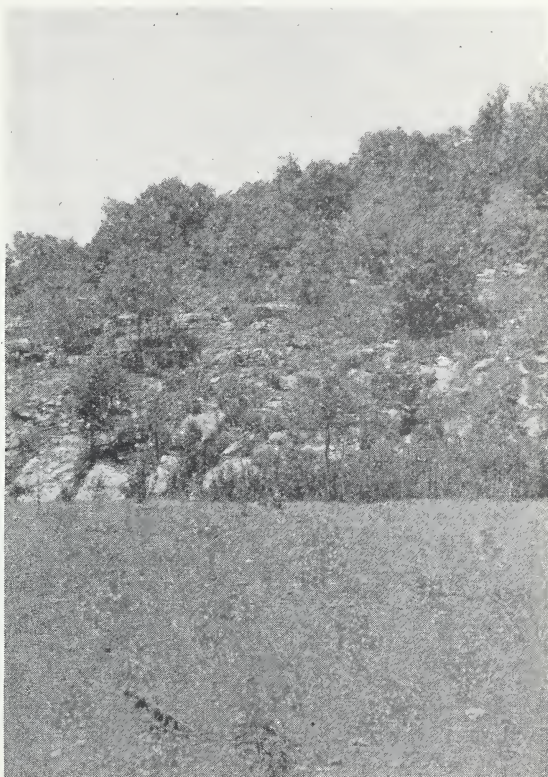


FIGURE 29.—A rocky slope and a filled basin, 5 miles southeast of Monticello, Wayne County. The owner, taking his cue from natural basins on his farm, which catch the soil, constructed a small dam across the stream channel and caught nearly all the soil lost from the slope. With its topsoil gone, the slope is no longer fit for cultivation.

occupation. It is rather flat on top and is bounded on all sides by abrupt cliffs, 10 to 15 feet high. The soil is a thin light-brown fine sandy loam, which supports a thick growth of hardwoods. Maples are most common, but there are several species of oaks (chiefly chestnut oak) and hickories that have attained large size. Dead chestnut trees are much in evidence. The understorey consists chiefly of dogwood, sassafras, and a few small pines.

2. Below the crest, on the outcrop of a band of shale, is an old field in which the second-growth timber has attained considerable size and density. The vegetation is almost entirely sassafras, dogwood, or young growth of hickory, oak, maple, tuliptree, and mulberry.

3. This is a pasture in which the contoured ridge rows of a corn-field cultivated 12 to 15 years ago are barely discernible. Shales and limestones outcrop and produce benches. The soil derived from shale has a gray silt loam surface 6 inches thick, which is underlain by a

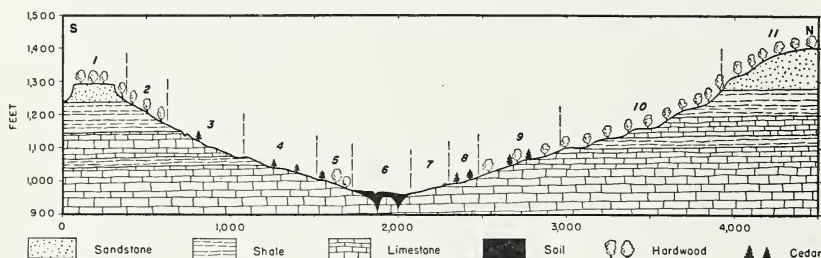


FIGURE 30.—Profile across Elk Spring Valley near Barrier, as shown in figure 28. The north-facing slope has largely been cleared and is alternately used for crops and pasture. When pastured it tends to grow up in brush, including cedar. The south-facing slope is in oak woodland, cut over but not cleared. The lower part of the slope has numerous cedars mixed with the oaks. The numbers above the profile refer to text descriptions.

mottled yellowish-brown clay or clay loam. The limestone soil is a light gray-brown fine sandy loam for 8 inches, becoming a dark red-brown clay loam beneath. In steep or disturbed places slumping and sliding of the A horizon over the B horizon can be noticed. The general slope is approximately 35 percent, and a few small dolines occur. The pasture was cleared of its cedar and persimmon shrubs 3 or 4 years ago and recently has been cleared again.

4. This field was taken out of cultivation and converted into pasture several years earlier than the field higher up on the slope. Although pasturing and occasional clearing have retarded the second growth, when observed in August 1936 the field was fairly well covered with persimmon bushes and cedars less than 10 feet high and with a sparse cover of grass. The owner then was engaged in clearing the pasture, and figure 31 shows it in cleared condition the following April. Although this part of the hillside slopes at only 20 to 25 percent, it is considerably more eroded than is the steeper slope above. Pitted limestone blocks are exposed at various depths, but are nearer the surface on the lower part of the field. A V-shaped gully, which begins in the area above, winds down slope and reaches a depth of 8 feet in the center of this area, after which it becomes shallower and finally fans out in the area below. The gully has only one or two minor tributaries.

Just east of the deep V-shaped gully is a circular gall about 40 feet in diameter, which has been reduced 3 to 4 feet below the general level. The margins of the gall rise to the general level of the field by a series of steps, each approximately 1 foot high. In the central, severely eroded area, incipient rills are present, but the dominant erosional process appears to be "mulch weathering" of the exposed B horizon. The loose fluff overlying the more compact soil attains a thickness of 4 to 5 inches. Much of this loose material is swept away by each succeeding rain, as is evidenced by the miniature pinnacles, erosion remnants an inch or so high, where the mulched soil has been preserved by capping pebbles (29, *pp.* 26-29).



FIGURE 31.—View southward across Elk Spring Valley near Barrier, April 1937. The view is along the line of the profile (fig. 30), which shows conditions in August 1936, after which time the hill slopes were cleared of brush and the valley field in the foreground was plowed. Scars and gullies are numerous on the lower slope, especially near the bottom. The numbers correspond to those above the profile in figure 30.

5. Near the site of a house, long since abandoned and fallen to ruin, there is an old garden and an orchard in which the trees are now dead. These areas are now grown up in a close cover of grass, weeds, blackberry briars, and persimmon bushes. A soil section showed 4 inches of a gray silt A horizon and 12 inches of a powdery buff silty clay B horizon overlying limestone. A short, 18- to 20-percent slope is cut by a rather shallow gully, which, nevertheless, reaches the limestone bedrock. The gully has grown up in weeds, cedar, persimmon, tuliptree, elm, cherry, and dogwood. It empties into the basin below, which has been filled largely by materials carried through the gully from the slopes above.

6. A basin, which is now part of a lespedeza hayfield, is filled to a depth of several feet with brown loam. That filling is still in progress is evidenced by a freshly made fan at the mouth of the gully entering the basin from above. A small sink has recently

opened near the center of this basin, which is separated from another at a slightly lower level by a small limestone ledge. Close to this ledge the soil is a powdery orange silty clay that becomes darker red in color and increases in clay content with depth. A boring to a depth of 42 inches did not reach bedrock, but the nearby outcrops indicate the proximity of rock to the surface.

The lower and larger basin, 175 feet in diameter and the lowest point on the profile (see dashed outline in fig. 31), was occupied by a small patch of sorghum when observed in 1936. Patch cultivation in the basins, where soil and moisture conditions are most favorable, is a characteristic feature of the Elk Spring Valley landscape. The soil in this basin is a brown sandy loam, becoming reddish-brown and clayey with depth. A soil section, taken near the edge of the basin, showed a darker-colored, buried horizon, apparently enriched with organic matter. Although no change in texture was evident, this may represent the original preagricultural A horizon, now covered with wash from the adjacent slopes.

7. The lower slope on the north side of the basin is about 15 percent. The soil supports a fair crop of lespedeza. A small gully crossing this field has been rather effectively stopped with cornstalks, leaves, and dead weeds held in place by a few rocks. The gully was caused by a road culvert that opened into the field. The road is at the upper edge of this zone.

8. The long slope from the highway to the northern ridge crest is clothed with timber. No resident can remember seeing or having heard of its being cultivated, but field observations indicate the possibility of at least the lower part once having been cleared. A relatively narrow strip just north of the highway has undoubtedly been cleared and probably has been cultivated. It is a typical cedar glade, containing trees 40 to 50 years old, growing on a rocky limestone surface.

9. On the next strip above, most of the soil has been removed, leaving large gray limestone blocks exposed as benches with scarps 4 to 5 feet high. The blocks are weathered differently above and below a plane 2 to 3 feet above the present soil surface. Above, the limestone is blocky, cracked, slabby, and crumbly from weathering. Below, it shows a smooth surface modified by rather fine diverging grooves, which apparently develop only under a soil cover and are present on the lower parts of the limestone blocks everywhere in this section. From this it is apparent that 2 to 3 feet of soil has been removed from the wooded slope, probably within the last century.

10. Above the limestone bench zone is oak-hickory forest growing on a thin limestone soil that is strewn with sandstone pebbles and boulders from above. Some of the trees are as much as 150 to 200 years old, their annual rings indicating several alternating cycles of good and bad growth conditions. Logging has been in progress, but there is no indication that this strip has ever been completely cleared. Benches are common, but, in contrast to the exposed limestone benches below, they characteristically have a soil cover.

11. The northern ridge crest is the outcrop of the Cypress sandstone. It is rather flat on top but is bounded by steep cliffs at its margins, as on the southern ridge. The extent of the sandstone on the north ridge, however, is greater both in area and height. The

vegetation is an old hardwood forest, consisting chiefly of oak, hickory, and maple. There are a few chestnuts.

Elk Spring Valley is a good illustration of the effect of direction of exposure on land use and soil erosion. The valley floor and the north-facing slope have been cultivated for more than a century, and there has been serious damage to the soil, even on the gentle inter-basin slopes. Where cultivation of the south-facing slopes has been tried, it has met with almost immediate disaster, and, except for a few small clearings, these slopes have been left in timber in recent years. Where east-facing and west-facing slopes are cultivated the damage is almost equally severe. Even north-facing slopes have not escaped erosion damage.

There are thousands of farms in the Kentucky karst with slopes similar to those at Barrier, and only a small proportion of the slopes can be tilled safely under the present system of farming. The district is still potentially productive but it will remain so only if the limitations of the area are recognized and the agricultural economy modified accordingly.

AGRICULTURAL IMPLICATIONS OF THE KARST

Agriculture, to be permanently successful, must be well adapted to local physical conditions. Karst lands require a unique type of agriculture, but insufficient attention has been given to this fact, as is demonstrated by the highly eroded condition of the Kentucky karst. The agriculture of the nonlimestone lands of Virginia and other coastal States could not properly be superposed on the karst landscape, yet this is essentially what the Kentucky settlers attempted to do. Taking advantage of the fertility of the limestone soil and the comparative ease of cultivation of the gently rolling surfaces, they intensively and rather disastrously exploited the karst lands. Row crops, especially corn and tobacco, were then and have continued to be the chief source of feed and cash.

PHYSIOGRAPHIC INFLUENCES

Physiographically, the karst differs greatly from regions having surface drainage. The lands of nonkarst regions are characterized by a network of interrelated valleys through which rills, streams, and large rivers carry the rainfall to the sea. Even the major streams flow on the surface of the ground. The drainage relief, or depth to which such an area can be readily dissected, is determined by the difference between the upland levels and the lowest elevation on neighboring stream courses. In karst regions water flows only short distances over the ground, because the surface drainage lines are broken by numerous basins, sinks, and dolines through which water passes downward and enters the underground drainage system of the area. The drainage relief in the karst is measured not by the depth of dissection of surface erosion as in nonkarst regions, but by the vertical distance from the uplands to these subterranean channels. The erosion potential in the karst is thus far greater than the gently rolling surface would indicate.

Careful farming of an area of high erosion hazard would suggest cultivating the fields on the contour, but a land surface cut with numerous small depressions separated by rounded knolls does not readily lend itself to contour cultivation. Farmers have found it easier to plow in straight rows, usually beginning at the fence lines. Under this system many of the furrows extend directly across solution depressions, and where the rows run up and down the slopes numerous small gullies have developed. If a field is laid off along the contours, however, the rows are necessarily very crooked, and, what is worse from the farmer's point of view, there are many short rows requiring frequent turning during cultivation. The sketch map of a 25-acre field near Lincoln farm indicates the nature of the difficulty of contour plowing in the karst (fig. 32). The field is of irregular shape as is common in this part of the country. For the last century the crops have been corn, wheat, and tobacco, and for

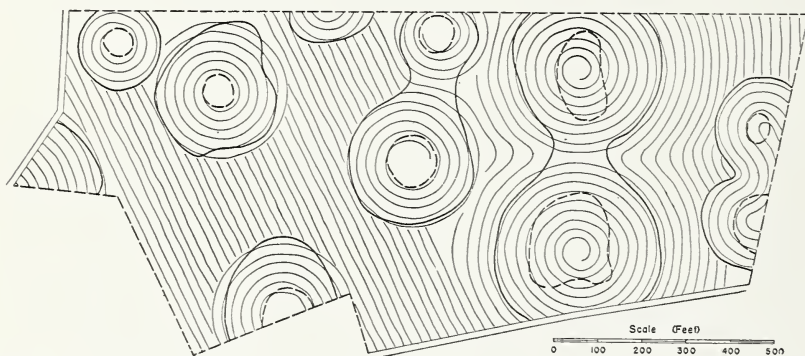


FIGURE 32.—Sketch map of a field near Lincoln farm with hypothetical furrow lines following the contours on the steeper slopes. This sketch is presented not as a solution of the problem but as an indication of the difficulties. The doline floors, inside the dashed lines, can be cultivated in any direction without damage, and there is little risk on the smooth uplands between the dolines; but the slopes below the heavy lines have lost much soil and obviously require a different treatment. They may be cultivated in spirals, as indicated on the sketch, but this will leave a number of short rows on the remaining land.

part of the time the field has been pastured or has remained idle. Eleven dolines, their bottoms ranging from 25 to 50 feet below the general level, lie wholly or partly in this field. The most severe erosion is on the slopes of the dolines, and if these slopes could be cultivated along the contours much soil would be held in place and kept out of the flat bottoms, where it is not needed.

The small size of some of the depressions makes them difficult to cultivate, but it is clear that where there are no cistern sinks the flat bottoms of the dolines require no special treatment unless drainage is necessary. Plowing might be begun at the bottom and spiral upward and outward until the margin is reached. The smooth upland with gentle slopes could then be cultivated in the most convenient manner. The scheme for plowing presented in figure 32 is intended to indicate the difficulty of plowing such a field rather than to offer a satisfactory plan. The problems of each field are different. Experimentation is necessary to determine how much the furrows may depart from the level without causing damage. Perhaps on the gen-

On steeper slopes a rough approximation of contour cultivation would be sufficient.

The karst landscape also presents peculiar obstacles to other methods of erosion control such as terracing and strip cropping. Construction of terraces is difficult where the slopes are short and the solution depressions are small. Terraces are better adapted to the longer slopes, but even there the danger of the opening of new fissures or sinks makes terracing a far more complex problem than it is in lands having only surface drainage. Strip cropping is a somewhat better method for use in the karst, especially on the longer slopes in the escarpment and knob lands on the karst margins. Some of the farmers have been using a crude form of strip cropping for many years; fences are run along the contours, and one field is left in pasture while another is cultivated (fig. 31). Improved strip cropping would provide many of the advantages of terracing on the long limestone slopes (18) and at the same time would not be so endangered by the development of cistern sinks.

Owing to the lack of adaptation of agriculture to physiographic conditions, gullying is very common in the karst lands. Almost every farm has gullies that need attention, and many attempts, often rather ineffectual, have been made to control their growth. There are two rather distinct types of gullies, one commonly developed on long steep slopes, and the other peculiar to the karst and found around cistern sinks on the level floors and marginal slopes of the basins. The first type responds to standard methods of gully control (25, 32), but the second presents a more difficult problem.

One method of control, locally successful, is applicable only to comparatively shallow gullies. The gully slopes are first reduced with the plow, then smoothed with a harrow or drag. The entire field, including the sides and bottoms of the gullies, is sown with grass or lespedeza, and the steeper gully slopes are covered with a thin layer of straw, staked down at intervals. Fertilizing the gullied areas before sowing promotes the success of this method. The practice of trying to check a gully by throwing in brush, straw, rocks, wire, or rubbish rarely succeeds.

Planting of trees in gullies, especially in fields which are no longer cultivated, helps to check erosion and stabilize gullied areas. The land is lost to cultivation, but the black locust and red cedar which are commonly used in gully planting grow well on the impoverished soils and provide wood for fence posts and other uses.

Gullying around the margins of cistern sinks in basin bottoms is very serious in some localities owing to the high erosion potential created by the difference of elevation between the land surface and the underground drainage. Control of erosion around sinks is one of the most difficult problems of the karst, because of the large amount of run-off that must be allowed to pass downward through these openings. Regulation of the run-off from the surrounding slopes helps to prevent enlargement of the sinks and reduces the hazard of gully cutting. Control of radial gullies usually is dependent on control of the cistern sink (figs. 33 and 34). One method is to fill the sink, but farmers often have found that when this is done fissures open in the tributary gullies and bring about the development

of new sinks. This may lead to the necessity of filling entire gullies—a very large and in many cases impracticable task. Although filling or closing of the sink aids in the control of gullying it may result in the formation of an intermittent or permanent pond in what is usually the most fertile part of the field.

A more satisfactory method of control was used successfully where water entering a deep cistern sink in an almost level field on a farm near Irvington had rapidly carved many gullies. The farmer placed



FIGURE 33.—A cistern sink near the center of a large basin 2 miles east of Irvington. Gullies about 6 feet deep were beginning to spread outward in several directions. In order to hold the water temporarily and check the gullies a 24-inch culvert pipe 8 feet long was placed in a vertical position in the sink. Rocks and brush have been piled around the pipe.

a culvert pipe, 24 inches in diameter, vertically in the sink (fig. 33) and piled blocks of rock around the bottom. This successfully raised the level of the inlet to the underground drainage. During light rains the water accumulated as a small pond, but in heavier rains the water level rose until the pond overflowed down the pipe. Soil which ordinarily would have disappeared into the underground channels accumulated in the floors of the gullies and checked further headward erosion. This adaptation of the drop-inlet culvert (25, fig. 26) to karst conditions shows great promise as a control measure. The size of pipe or tile can be selected according to the amount and rate of run-off to be passed.

If the upper end of the pipe is set slightly higher than the bottom of the basin some of the water will be prevented from escaping and will have an opportunity to soak into the soil. A screen can be provided over the top of the pipe to keep out rubbish, and, if the field is pastured, a fence should be constructed to keep livestock away from the inlet.

Many of the basins in the Kentucky karst have been so filled by material eroded from the surrounding slopes that there is now no cistern sink to carry away the accumulated run-off. If the bottom fill is thin, water flowing into the basin may seep downward as fast

as it enters. As more fine sediment is carried in, however, ponding takes place,⁹ the time necessary for the water to escape is increased, and the crops may be ruined by the standing water. Many roads, including even such important thoroughfares as the Dixie Highway, have been blocked for hours or days by these temporarily ponded basins. Farmers often attempt to open the bottoms of flooded basins. Sometimes this can be accomplished with a crowbar or a post-hole auger; sometimes dynamite is required. Whichever method is used the outcome is uncertain. The basin may pond again the following year or the opening may be so enlarged that a permanent sink is formed and a system of tributary gullies induced.



FIGURE 34.—A broad gully head in a flat-floored basin about 1 mile east of Irvington. Limestone is exposed only at the head of the gully near the margin of the basin. A buried soil profile indicates that the basin was first filled by erosion of the surrounding slopes (attested by hillside gullies), after which cistern sinks were opened in the bottom. From this lowered base, this gully, from 12 to 20 feet in width, 4 to 10 feet in depth, and 250 feet in length, has been formed in about 30 years.

It has been said repeatedly of badly eroded areas "such land should never have been cultivated." Some of the steeper and longer slopes of the Kentucky karst are doubtless better suited to woodland and pasture, but the greater number of the slopes are neither very steep nor very long. The physiographic forms peculiar to the karst present unique erosion problems, but the more enterprising farmers have demonstrated that most of these hazards can be overcome by a planned program of erosion prevention and control. The erosion problem in the karst is all the more serious, though, because the rounded slopes and the absence of surface streams give an impression

⁹ UNITED STATES GEOLOGICAL SURVEY. HARDINSBURG (KY.) QUADRANGLE. Scale, 1:62,500; contour interval, 20 ft. 1931.

— BIG CLIFTY (KY.) QUADRANGLE. Scale, 1:62,500; contour interval, 20 ft. 1932.

of stability to the landscape. As a result, much damage is done before the danger is realized.

The more serious soil erosion in the Kentucky karst is decidedly spotty in distribution, but soil has been lost from all surfaces except the bottoms of some of the depressions. The greatest risk in the doline karst is on the lower, steeper slopes of the dolines. Up the slopes, soil removal becomes progressively less. In the basins, erosion is most severe along the outer margins, where the slopes are steepest. On the long slopes of the escarpments bordering the upland and upland remnants the damage is greatest near the bottom.

SOCIAL INFLUENCES

The physical problems of the limestone lands of western Kentucky are complicated by human factors. Many of the farmers show a marked lack of concern about erosion. Tenancy has increased and as the tenant's status is uncertain from year to year he is not inclined to expend much effort in stopping gullies or growing cover crops on another man's land. Although the percentage of tenancy is not so high as in the Cotton Belt or even in parts of the Corn Belt, the recent increase in many counties in the percentage of harvested cropland farmed by tenants has been rapid, as is indicated in table 3 (34).

TABLE 3.—Percentage of harvested cropland farmed by tenants in 10 selected Kentucky counties, 1924, 1929, and 1934

County ¹	1924	1929	1934	County ¹	1924	1929	1934
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>		<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Barren.....	23.1	29.1	32.9	Logan.....	34.7	32.8	38.9
Christian.....	36.8	43.0	40.0	Meade.....	19.4	24.3	24.6
Hardin.....	23.7	24.9	26.8	Simpson.....	43.3	42.0	51.7
Hart.....	20.8	29.6	33.0	Trigg.....	37.4	39.6	43.6
Larue.....	17.0	22.1	21.9	Warren.....	34.4	29.3	30.0

¹ For location of counties, see fig. 4.

Tenants, however, are not the only ones who shift from farm to farm. Some of the farm owners also seem to have the impression that when one farm is exhausted another can be obtained without difficulty, and in some localities, unfortunately, it is still a mark of industry rather than a disgrace to "wear out a farm." This improvident attitude toward the land is occasioned, in part, by the slowness with which erosion makes its appearance and by the fact that the early stages are not conspicuous. The transient farmer has little interest in erosion control unless it will show some immediate profitable results. On the other hand, if a farm has been in one family for generations, or if the occupant is determined to make it a permanent home, there is likely to be a sincere effort to control erosion. The situation is not unlike that in Virginia, described by Hall (13). In both sections farsighted farmers developed methods of erosion control that were locally effective. Often these failed when put into general use, not because they were intrinsically faulty but because their range of applicability was limited by environ-

mental conditions. On one farm, revegetation that involved the use of cover crops immediately following row crops was sufficient. Another farm might require contour tillage, terracing, or strip cropping. In the karst lands the full value of past erosion-control experience of practical farmers can be obtained only when that experience is analyzed in the light of a knowledge of the karst-forming processes.

Even if all farmers were sincerely concerned with preventing soil erosion and understood the best methods of protecting their lands, there would remain the difficulty of financing the rehabilitation of the farms. The income of most farms is not sufficient to finance a comprehensive scheme of erosion control, and most of the farmers of western Kentucky have employed only those control methods that require little or no cash investment. Many farmers can scarcely afford the crushed limestone or cheap fertilizer needed to produce a good cover crop on washed land. An increase in farm income, in terms of higher prices for farm commodities, would probably only tend to increase row-crop acreage and accelerate erosion. It is encouraging to note, however, that in nearly every community a few of the best farmers have maintained their land in fairly good condition.

LAND USE FOR THE KARST

Experimentation with new crops and new land use should point the way to better adaptation of man to the land. The karst areas have possibilities for development far removed from present trends in land use. For example, some of the larger basin bottoms could easily be converted into ponds or small lakes in which fish and fowl could thrive. A few ponds of this sort have been formed, unintentionally, by silting up of basin floors, following excessive cultivation of the surrounding slopes, and are now yielding fish for the farmer's table and cash returns from the sale of fish and the fishing privilege. It is not necessary to destroy upland soil in order to produce ponds; pasturing or feeding livestock in the basin bottom will quickly compact the fine soil and render it impervious to water. Many European farmers in similar areas alternate land farming with water farming, each of which contributes to the productivity of the other (24, pp. 65-67). This is but one of a number of ways in which land use could be adapted to the physiographic characteristics of the limestone lands.

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<i>Division of Research</i> -----	W. C. LOWDERMILK, <i>Chief.</i>

